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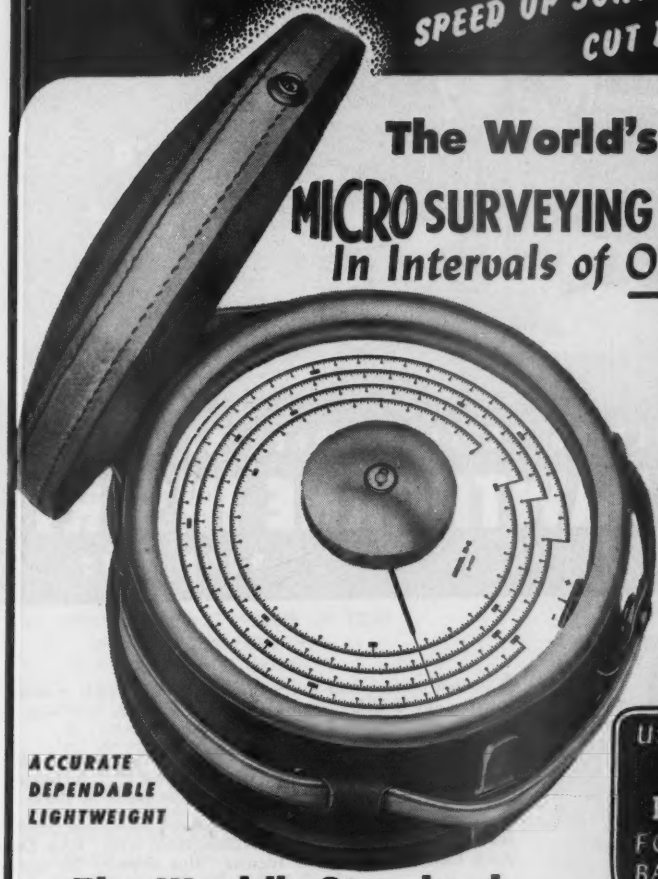

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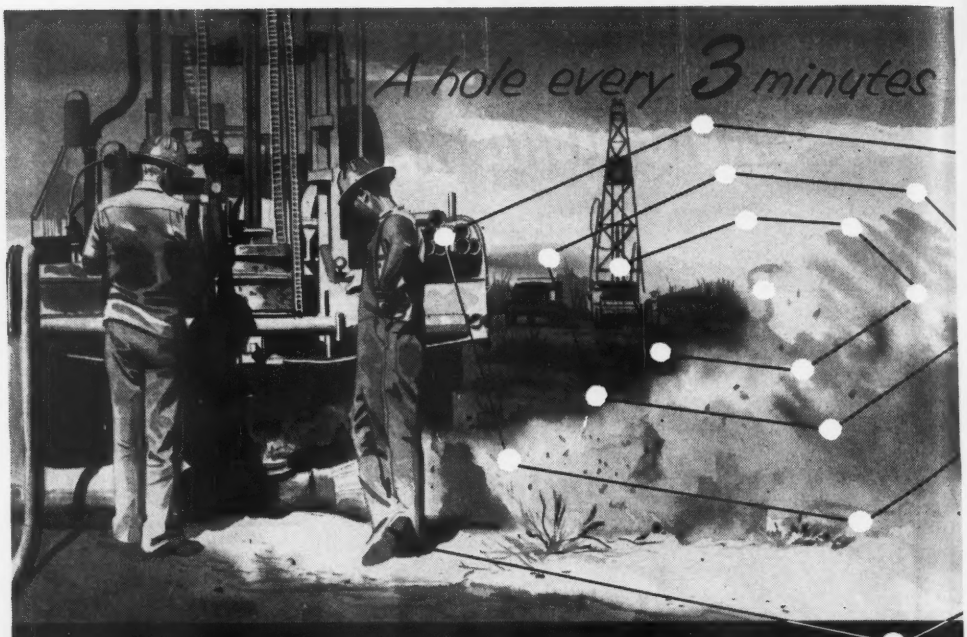


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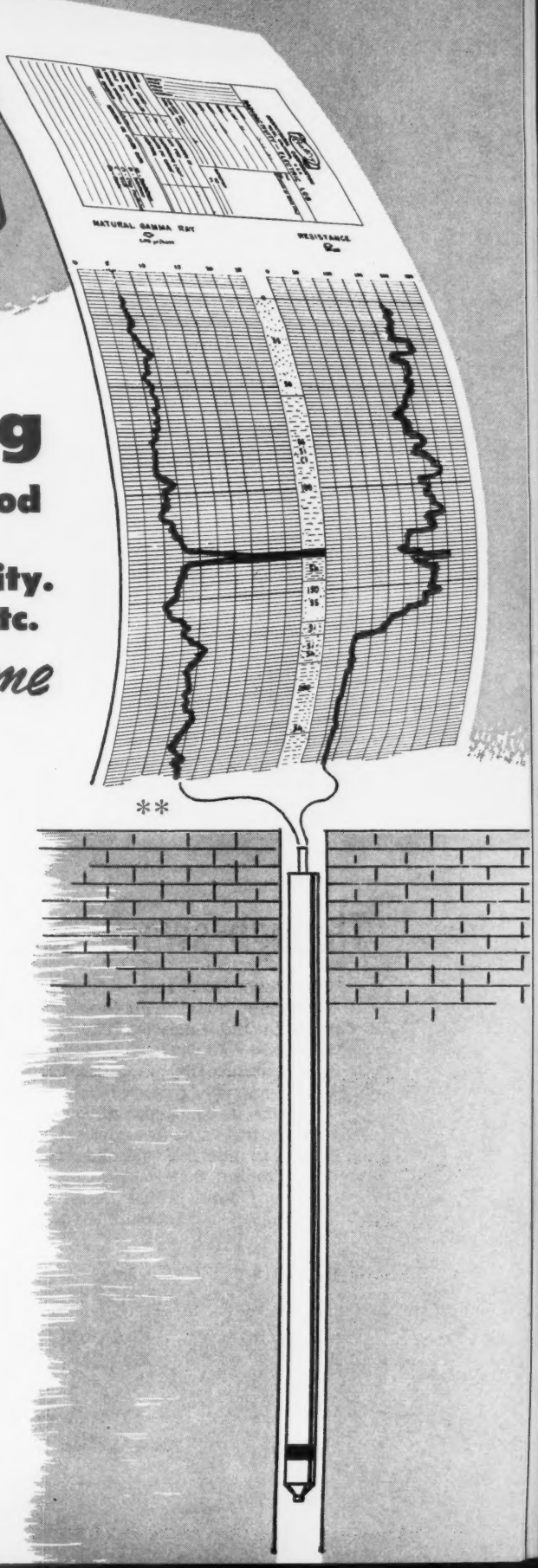


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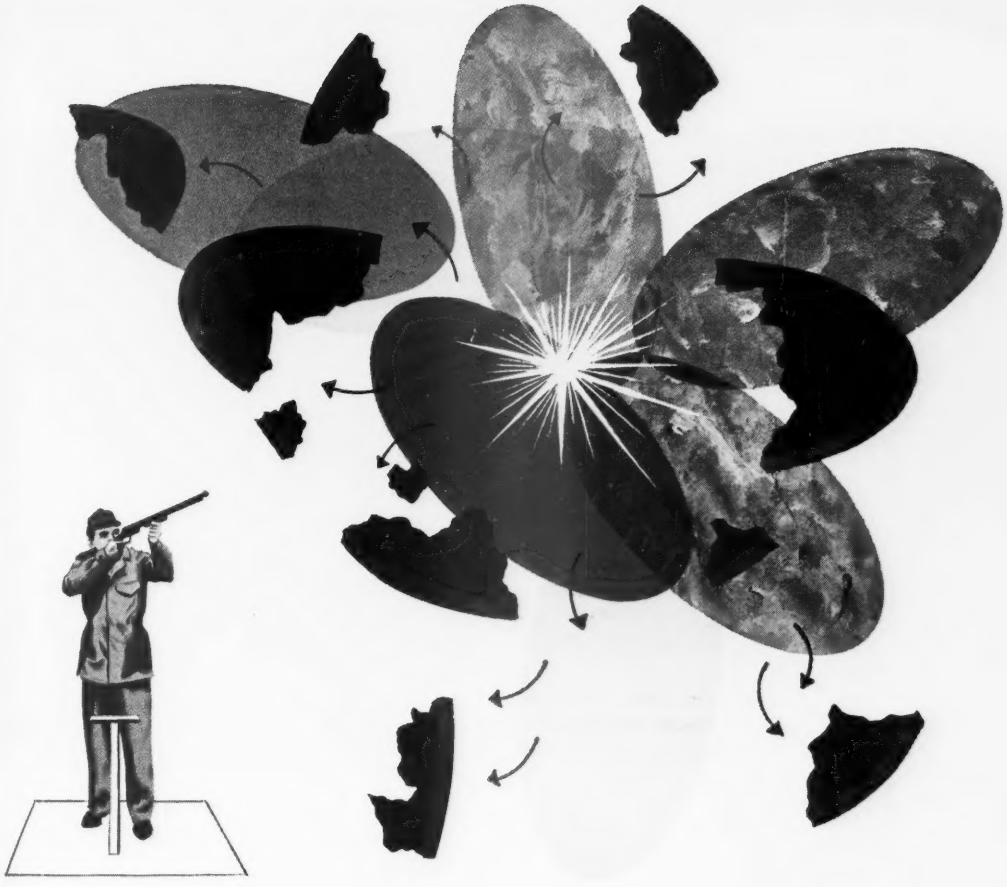

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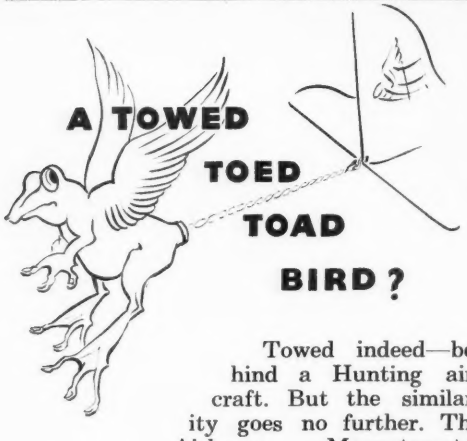

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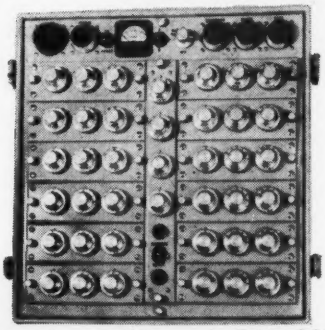

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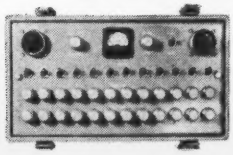

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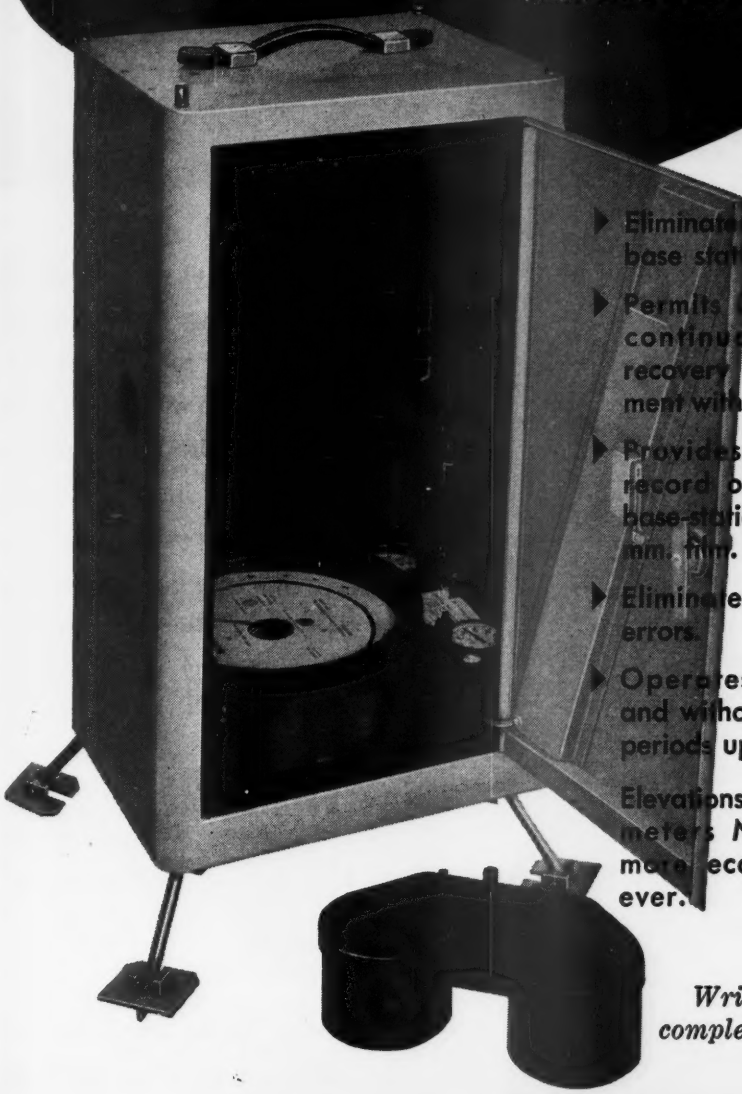

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VOLUME XX APRIL, 1955 NUMBER 2

# GEOPHYSICS

## TECHNICAL PAPERS

### NOTES ON THE USE OF MULTIPLE GEOPHONES*

LEONARD V. LOMBARDI†

ABSTRACT

The use of multiple geophones, which has been largely empirical, serves two primary functions: cancellation of random and other unwanted energy, and improved sampling of the wave front. Curves are presented showing effectiveness of several different spreads for surface-wave cancellation. The results also apply to mixed records. Cancellation of random energy follows conventional sampling theory, varying with the square root of the number of geophones in the spread. Sampling of the wave front is more complex because the samples are not mutually independent.

#### INTRODUCTION

After shooting and re-shooting areas of good records, more and more seismograph crews are finding themselves in areas which were until recently considered unworkable by the reflection method. Most of the crews working in these difficult areas have found it expedient to use multiple geophones.

In general, the writer's experiments with these detectors have been empirical; two to thirty-six, and occasionally sixty-four, geophones were used for each trace, and the spacing, type, and orientation of pattern were varied until, ordinarily, improvement of record quality was obtained. This is believed to be a fairly common practice, but it is not necessarily an efficient procedure. The rather limited investigations on which this paper is based were carried on with the object of putting the use of multiple detectors on a more scientific footing. They have yielded some results which have been useful to the writer, and it is hoped that these notes may suggest some concepts pointing toward use of multiple geophones in a more systematic way.

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† Gulf Oil Corporation, Fort Worth, Texas; formerly with Stanford Research Institute, Stanford, California.

## REASONS FOR THE USE OF MULTIPLE GEOPHONES

Two reasons for the use of multiple geophones appear to be basic; both, of course, involve improvement of signal-to-noise ratio. First, they may partially cancel unwanted systematic energy and so-called random energy, including wind noise and ground unrest. Secondly, they may yield a better sampling of an irregular wave front, or improve the average coupling between geophone and ground. The use of multiple geophones as a means of increasing the total energy is not considered here; it would seem that this may better be accomplished by redesigning the geophone and/or amplifier.

## RANDOM ENERGY

In previous analyses (Jenkins and White, 1950, p. 210–211) the general conclusion has been reached that the effectiveness of a spread in cancelling random energy varies with the square root of the number of geophones used. It is convenient for present purposes to arrive at the same result from the viewpoint of sampling theory. Whereas we do not in general expect to cancel random energy, we may reduce its effects on seismic measurements, be they arrival times, amplitudes, or periods. From this point of view, superposed random energy simply results in a region of uncertainty—a zone of error so to speak—about the true value we are attempting to measure. Elementary sampling theory is applicable to this model. The familiar result, of course, is that a very large number of single measurements (samples) will be distributed in a normal curve about the true value (which is the center of the distribution) with a standard deviation $\sigma$; the means of a number of groups of $n$ samples will be distributed about the true value with a standard deviation $\sigma/\sqrt{n}$. It matters not whether the sampling is distributed in time (e.g., successive measurements taken from repeated shots) or space (e.g., simultaneous measurements of the same portion of a transient at several different locations). Ideally, geophones fall within the latter category: each contributes a sample, and the reduction of uncertainty ("the improvement") varies with the square root of the number of detectors. We assume proper samples and truly random energy.

We should note, however, that the term "random energy" is ordinarily used rather loosely to denote that energy which occurs at such times on a record that the response of a given trace in the energy band cannot be predicted by study of the other traces. An apparently random disturbance recorded with a geophone spacing of 146 feet (Figure 1) may show a systematic nature when recorded with another geophone spacing. Figure 2 shows the disturbance of Figure 1 as recorded with a $2\frac{1}{2}$-ft geophone spacing. The "random" disturbance actually consists of a number of high-frequency transients, whose low apparent horizontal velocities are noted on the record. Hence the term "random" is used here in a relative time-distance sense, a usage which has no genetic or mathematical implication. When the nature of a disturbance is known, as in the case illustrated, it may be possible to cancel it without using an excessive number of geophones.

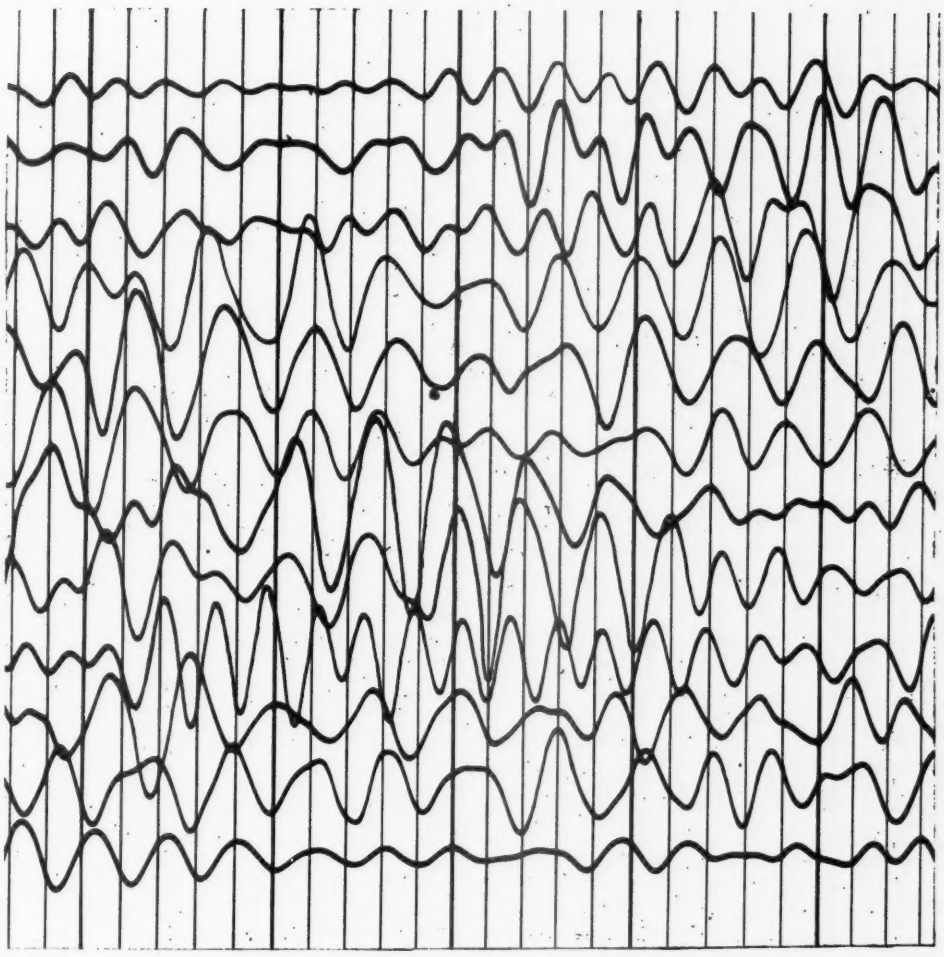

FIG. 1. "Random" disturbance recorded with single detectors 146 feet apart.

## IRREGULAR WAVE FRONTS

A more complex problem is that of sampling an irregular wave front. The effective wave front arriving at the surface may be irregular for a number of reasons. These include inhomogeneities in the shallow section (the acoustic analogs of optical striae and accompanying scintillation), interference effects, possible phase changes associated with more or less acoustically isolated near-surface blocks, etc. One may imagine an ideal "true" reflection as an average surface passing through the observed irregular wave front. In practical interpretation, one ordinarily assumes that each trace on the seismogram represents a portion of this average surface. If the actual wave front is irregular, there exists a low probability that the sample obtained by one geophone coincides with the portion

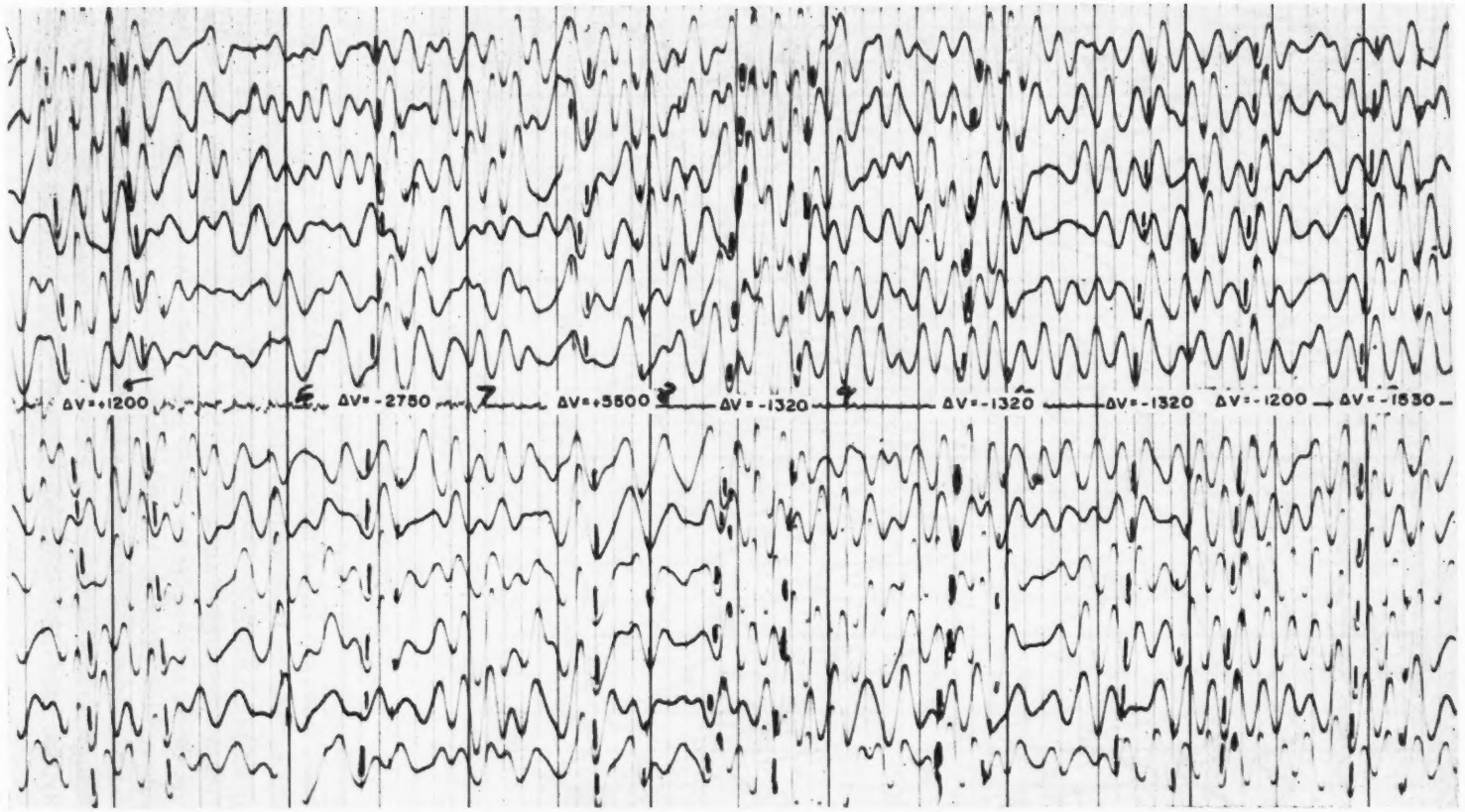


FIG. 2. Record obtained in the area of the disturbance shown on trace 9 of Figure 1, but recorded with single detectors $2\frac{1}{2}$ feet apart. Numbers are apparent horizontal velocities in ft/sec.

of the *mean* wave front arriving at that geophone. Hence it is possible that, due to poor sampling, the arrival times associated with a reflection at the different geophones of a spread may have enough irregular variation to make the reflection unreadable on the resulting record. We normally would like the probability to be high that the sample arrival time shown by a trace approaches reasonably closely the arrival time of the ideal "true" reflection at the geophone corresponding to that trace.

The elementary sampling procedure mentioned in connection with random energies does not apply to this problem for a number of reasons; probably the most important is that it requires mutually independent samples. The effective arriving wave front must be a continuous surface and not an infinite number of discrete independent points. The outputs of two detectors placed in close proximity cannot be mutually independent. If the detectors are separated by a distance large with respect to the lateral extent of variations in the arriving wave front, the samples may approach mutual independence. Hence a compromise must be reached between the wide spacing desirable to average out irregularities in the wave front and the fact that excessively wide spacing will partially cancel a nonhorizontal reflected wave front.

Reflected waves have been studied in some areas with very close geophone spacing to obtain quantitative data on the irregularity to be expected. In several areas these studies have shown how suprisingly small is the lateral distance required for the erratic variation in the arrival time of the effective wave front to approach its maximum. These experiments were not carried far enough to permit one to reach general conclusions. However, data of this sort may enable one to determine near-optimum spacing for a given area from a study of the wave-front irregularity and from consideration of the maximum reflection stepout to be expected. When detector spacing is large with respect to the lateral extent of irregularity, the problem may be treated, for practical purposes, by elementary sampling methods. Using this approach, one can show that improvement varies approximately as the square root of the number of detectors.

### ERRATIC PLANT

A related sampling problem involves areas in which caverns or other irregularities in near surface formations result in "dead" spots on the surface at which little or no energy is detected. In extreme cases, moving the geophone two feet may make the difference between a live and a dead trace. Here the sampling problem is to obtain a high probability that one or more geophones of a group is on a "live" spot. If the likely dimensions and areal density of "dead" spots are determined by experiment, detector grids may be designed to achieve any desired probability; this procedure is probably carried out analytically or empirically by most, or perhaps all, of the crews operating in such areas at the present time.

It seems likely that this "dead-spot" problem is ordinarily a special (and extreme) case of the more general problem of variations in coupling of geophone

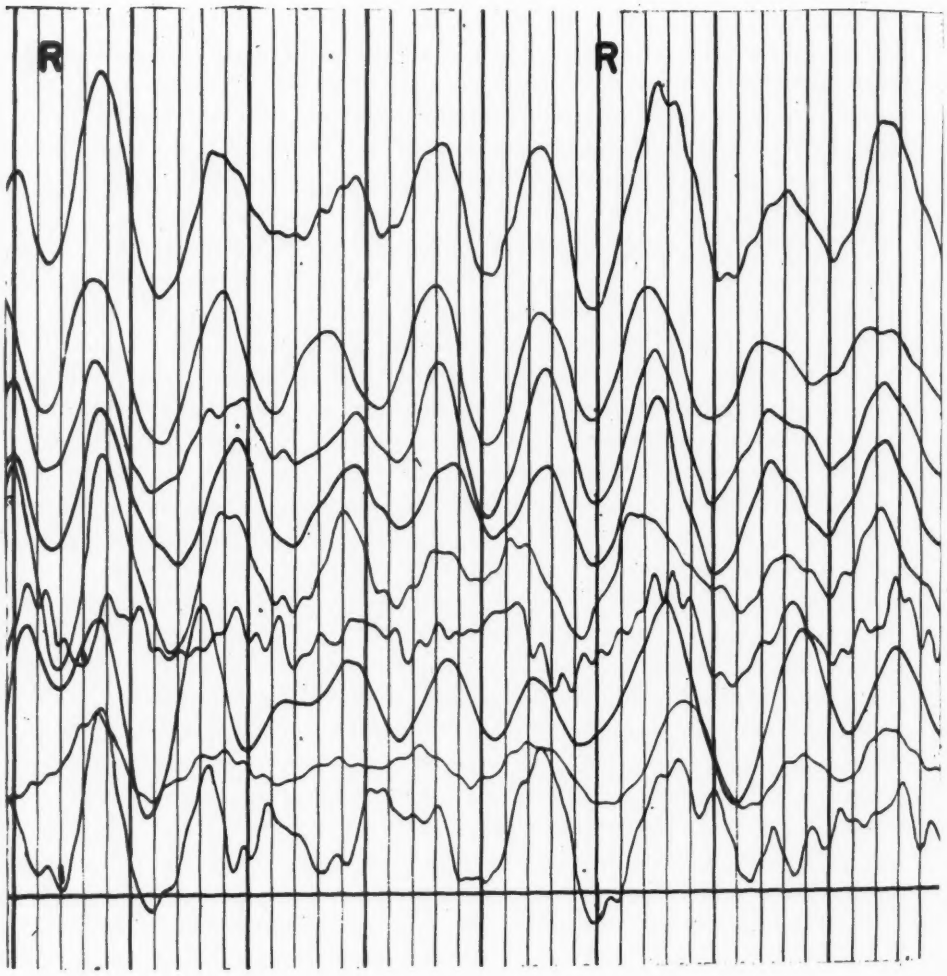


FIG. 3. An example of variations of geophone plant. The upper trace is the compounded output of eight geophones. The lower traces are the outputs of single geophones planted beside the members of the compounded group. Reflections, marked "R", are based on continuous coverage.

to ground, which we may term the "plant problem." As example of an erratic plant is shown in Figure 3, which is a portion of a record from an area in West Texas. The upper trace is the compounded output of eight geophones spaced ten feet apart. Two reflections, picked on the basis of continuous coverage at this location, are marked. The remaining traces are the outputs of single geophones planted beside each geophone of the multiple group. All outputs were recorded without AVC. Care was exercised to make the plants as uniform and as nearly perfect as possible. There was considerable wind disturbance at the time the record was taken.

It will be noted that the outputs of several of the single geophones are practically identical to the output of the multiple group. Hence a single detector would have done as well as the entire group if there had been some way to tell where to plant this single detector before the shot was fired. Other outputs are noisy, and several indicate somewhat different arrival times. In this case, then, the use of multiple geophones is a convenient way of making it probable that there will be one or more good plants for each trace, and of averaging out the effects of bad plants.

More extreme variations of plant have been observed, including some in which the output of one geophone was so large, apparently due to favorable coupling, that it completely dominated the outputs of the other members of the group. This observation appears to have implications in connection with sampling, and also, perhaps, in connection with the occasional mysterious bursts of energy and irregular first arrivals that may be observed when multiple geophones are used.

## CANCELLATION OF HORIZONTAL WAVES

The other reason for the use of multiple detectors is the cancellation of horizontal waves. (It is readily admitted that this division is somewhat artificial. The plant problem is obviously a consideration in any use of multiple detectors, and the horizontal wave problem is inseparable from that of irregular reflected wave fronts.)

It is well known that in theory one can place two detectors a half-wave apart and cancel horizontally travelling surface waves. In practice, of course, it is equally well known that a half-wave plant is seldom achieved, due to varying frequency spectrum, velocity, and angle of incidence of the horizontal disturbances. Hence one obtains a partial cancellation which varies with the apparent wave length of the disturbance; this is also true when larger numbers of geophones are used. It is not quite so obvious that variation of cancellation with wave length amounts to a filtering effect, with a response characteristic showing a number of peaks and troughs (Johnson, 1939; Olson, 1947, p. 26–40). We shall endeavor to determine the response characteristics of a few simple geophone plants to horizontal disturbances.

The steady-state condition is considered, and it is assumed that horizontally incident energies are pure sine waves, that the detectors are planted at equal intervals along a line, and that coupling to ground and ground response are the same for all geophones. A measure of the cancellation efficiency of a multiple geophone spread is the ratio of the maximum recorded amplitude of horizontally traveling disturbances, divided by the number of geophones, to the maximum amplitude that would have been recorded from a single geophone. This is equivalent to comparing the recorded amplitude for the vertical components of vertically incident *P* waves and horizontally incident surface waves. The ratio may be considered to be an inverse cancellation factor; a value of one indicates no cancellation and a value of zero indicates complete cancellation.

The response curves have been worked out for lines of 2, 4, and 9 geophones and, as a limiting case, for a continuous-line detector (i.e., an infinite number of geophones within a given spread length). For these spreads, and under the imposed conditions, the response, $f$, for $i$ geophones is of the form:

$$f_i = (1/i)\left|\sum_{n=0}^{(i-1)} \sin\left[A + 2n\pi d/(i-1)\lambda\right]\right|,$$

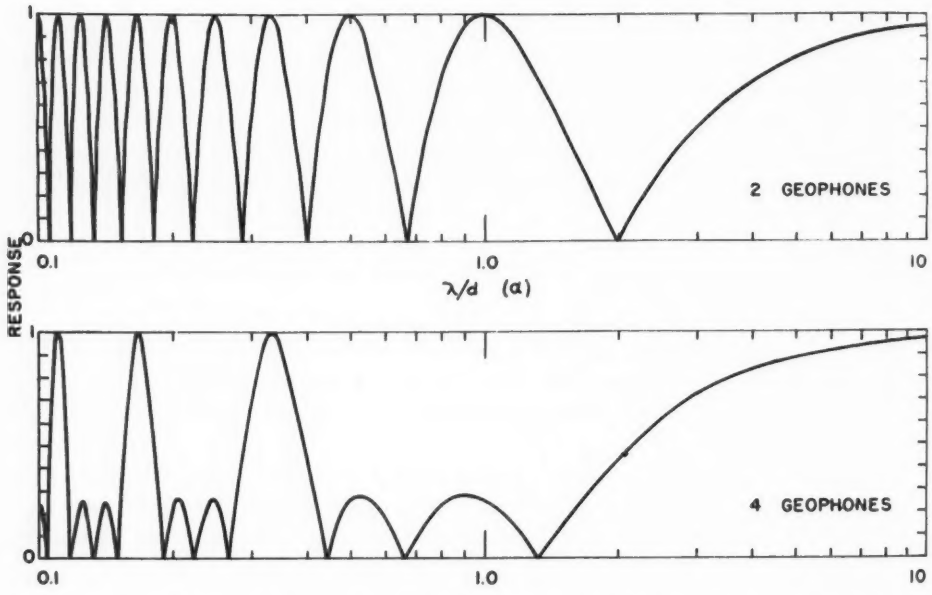


FIG. 4. Response of two- and four-geophone line spreads to horizontal waves. The quantity $\alpha$ is defined as the ratio of the wavelength, $\lambda$, to the geophone spread length, $d$.

where $d$ is the length of the multiple geophone spread, $\lambda$ is the wave length of the horizontal disturbance, and $A = (\pi/2 - \pi d/\lambda)$.

For a continuous detector, extended in the $x$ direction, the response formula becomes:

$$f_\infty = (\lambda/2\pi d)\left|\int_{\pi/2-\pi d/\lambda}^{\pi/2+\pi d/\lambda} \sin x\, dx\right|,$$
$$= \left|(\lambda/\pi d)\sin(\pi d/\lambda)\right|.$$

To keep the results general, response is plotted in terms of the quantity, $\alpha$, defined as the ratio of wave length to the length of a geophone group. Wave length in this case refers to apparent horizontal wave length in direction of the geophone spread.

A simple adjacent-trace mix amounts in effect to a two-detector multiple-

geophone array when single detectors are used, or to a two-unit array when multiple detectors are used, unless the multiple geophones are spaced to give continuous ground coverage, in which case this mix simply doubles the spread length. Double adjacent trace and wedge mixes are in effect longer multiple geophone arrays to which the outer geophones may contribute only part of their outputs.

Figures 4 and 5 show the calculated response curves for groups with various numbers of geophones. All of the multiple-geophone spreads act as filters, since response depends on wave length. With a two-geophone spread, the filter is rather sharp, and the geophone spacing is critical. Some of the frequency components of

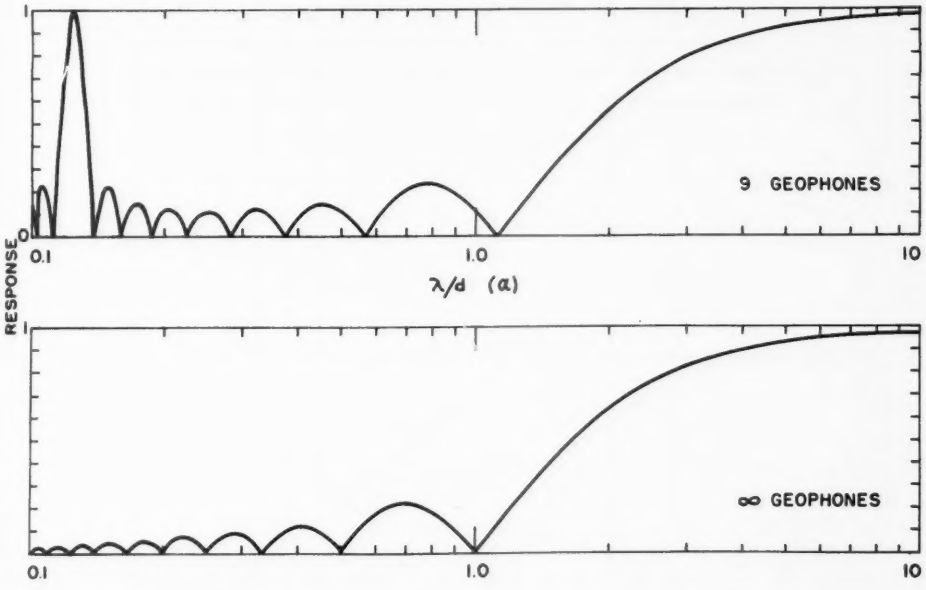


FIG. 5. Response of nine-geophone and continuous (infinite number of geophones) line spreads to horizontal waves. The quantity $\alpha$ is defined as the ratio of the wave length, $\lambda$, to the geophone spread length, $d$.

a disturbance may be recorded with no cancellation, while others are completely cancelled, giving a quasi-resonant effect. As the number of geophones is increased, subsidiary peaks of partial cancellation enter between the major peaks so that considerable reduction is obtained over a wider range of apparent wave length, and the quasi-resonant effect (i.e. no cancellation when the wave length equals the spacing between elements of the geophone group) becomes less important. With a continuous line plant, it disappears completely.

Figure 6 shows curves representing $\alpha$ values for complete cancellation (with the shortest possible geophone spreads), and the upper and lower 50% cancellation limits, for different numbers of geophones. The broader cancellation range obtained by the use of more geophones in a given spread length is apparent, this

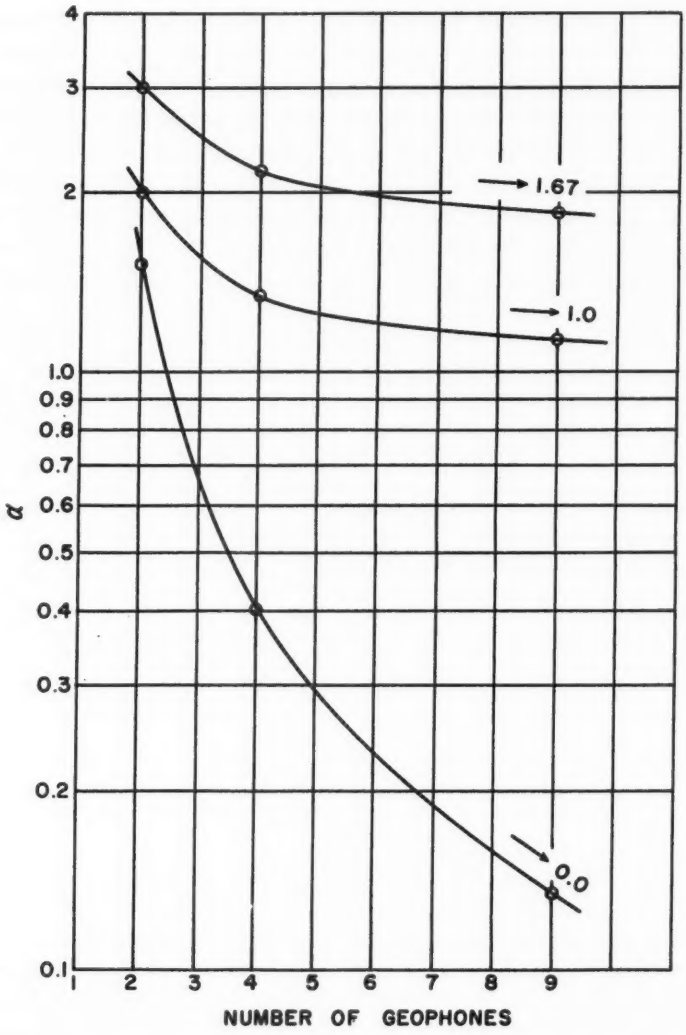


FIG. 6. Center curve gives values of $\alpha$ for complete cancellation of horizontal surface waves with minimum geophone spread length. Upper and lower curves are adjacent fifty-percent cancellation limits. Limiting values are reached by a continuous spread. The lines connecting the points are for visual clarity, and do not imply continuity.

being, of course, a reflection of more favorable response curve envelopes. It is also apparent that for cancellation, with the exception of a two-geophone spread, it is better to err in the direction of making the spread too long ($\alpha$ value too low) than of making it too short.

As with sampling, this desirability of long geophone spreads must be balanced against the fact that reflections incident at an angle other than vertical may have

appreciable apparent horizontal wave lengths, and thus may be affected by the multiple geophone spread. In practice, the apparent horizontal wave lengths of surface disturbances and probable reflections may be calculated rather simply after observation in an area, and a compromise geophone spread selected.

These curves have been discussed in terms of a line geophone plant. In order to cancel disturbances incident to the recording spread at an angle, a two-dimensional geophone pattern is customarily used. The response curves may be applied to simple patterns, at least to a first approximation. For example, on Figure 7, wave A sees a two-geophone spread. Wave B sees a four-geophone spread. To wave C, the pattern is effectively a six-geophone line in which two central pairs of geophones are parallel to the wave front, and hence must be

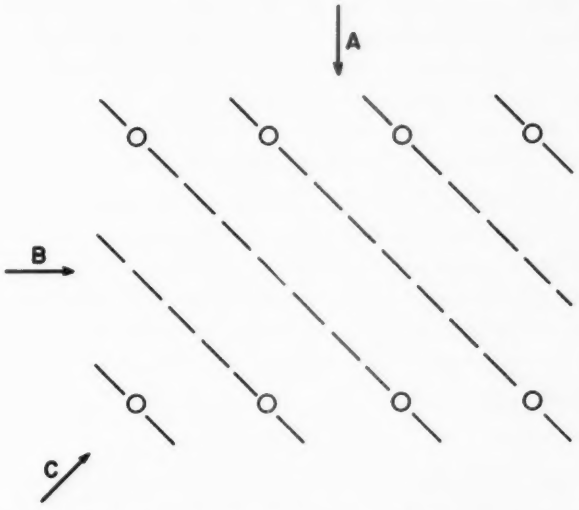


FIG. 7. Simple eight-geophone two-dimensional pattern. A, B, and C represent ray paths of incident waves. The dashed wave fronts are associated with event C.

weighted as a single geophone with double the normal output. The effect for other angles of incidence may be worked out in a similar manner. As response is a continuous function of angle of incidence, reasonable interpolation may be made when the primary responses have been determined.

These response curves are of some interest in other connections. The effect of superimposing the detector group filter on the amplifier filter may be advantageous or deleterious, depending on the constants involved. Also curves of this type may be used to study the effects of mixing on angular reflections and surface disturbances. It may be noted that the effects of multiple-trace mixing and intricate detector patterns appear to be rather complex, perhaps more so than would appear at first glance.

## SUMMARY AND CONCLUSIONS

These notes have dealt with some thoughts and experiences concerning the use of multiple geophones. Multiple detector groups may be used as a means of improving the sampling obtained with one geophone, or as a means of cancellation of unwanted energy. In the former case, elementary sampling theory appears applicable, at least to a first approximation, to the design of the detector array that will insure, to a reasonable degree of certainty, that the output gives a representative sample. In the latter case, the use of rather long spreads and a large number of detectors greatly increases tolerance to variations in the surface wave to be cancelled. Indeed, it would appear that the upper limit of the number of geophones to be used in a given area is determined by economic rather than by theoretical considerations. However, it is believed that the efficiency with which a given number of geophones can be used may vary quite appreciably.

The investigations reported here are quite limited in scope, but they indicate a number of the considerations which apply to the use of multiple geophones and which may be of help in planning field operations.

## ACKNOWLEDGMENTS

The notes reported here are based on field work done over a period of several years by an experimental seismograph crew from Stanford Research Institute; the writer wishes to express appreciation both to Stanford Research Institute and to Gulf Oil Corporation for permission to publish this paper.

The writer is also indebted to Stanford Research Institute for material assistance, and for ideas generated in technical discussions with members of its geophysical staff.

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GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955), PP. 227–242, 14 FIGS.

# MODEL SEISMOLOGY—THE CRITICAL REFRACTION OF ELASTIC WAVES*

P. N. S. O'BRIEN†

## ABSTRACT

Model experiments on the head wave are described. Quantitative data are obtained for three different pairs of media: light lubricating oil on top of a saturated solution of calcium chloride, water on top of wax, and water on top of concrete. Within the limits of experimental error these data agree with the theoretical prediction that the head wave should decay with distance as $r^{-1/2}L^{-3/2}$ (Heelan, 1953).

## INTRODUCTION

It has long been known that in the case when a medium of higher velocity underlies one of lower velocity, energy follows a ray path which is incident on the interface at the angle of critical reflection, travels along the interface with a velocity characteristic of the lower medium, and continually re-emerges into the upper medium, again at the critical angle. This is illustrated in Figure 1.

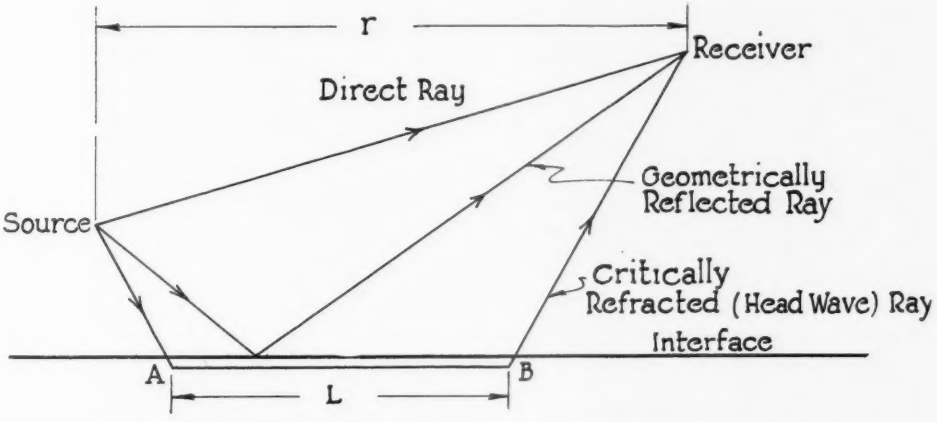


FIG. 1. The direct, geometrically reflected, and critically refracted (head wave) rays.

In exploration seismology these waves are usually called refracted or, perhaps more correctly, critically refracted waves. However, as the adjective "refracted" normally refers to the lower medium, the term *head wave* (Heelan, 1953; von Schmidt, 1938) is used in this paper.

Cagniard (1939) and others—Ott, 1941 and 1949; Gerjuoy, 1953; Heelan, 1953—have shown analytically that the decay of amplitude with distance should

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be proportional to $r^{-1/2}L^{-3/2}$, where $r$ is the orthogonal projection on the interface of the distance between the source and detector and $L$ is the distance the wave has travelled in the lower medium.

These workers have also shown that the form of the head wave is related to the form of the initial generating wave, as a function is related to its time derivative (see, for instance, Heelan, 1953, p. 882), and that the displacements in the case of a dilatational head wave are directed along the ray.

Excellent experiments on the head wave have been reported in the literature. Von Schmidt (1938) obtained schlieren photographs which clearly showed an acoustic head wave, and H. Maecker (1949) obtained many quantitative data on an optical head wave.

In order to check the predictions of theory for elastic head waves—in particular the law of decrease of amplitude with distance—some laboratory experiments were conducted which are reported on below.

## EXPERIMENTAL METHOD

Most of the theoretical analyses of the problem of head waves have been developed for homogeneous, isotropic, infinitely extensive slabs in contact

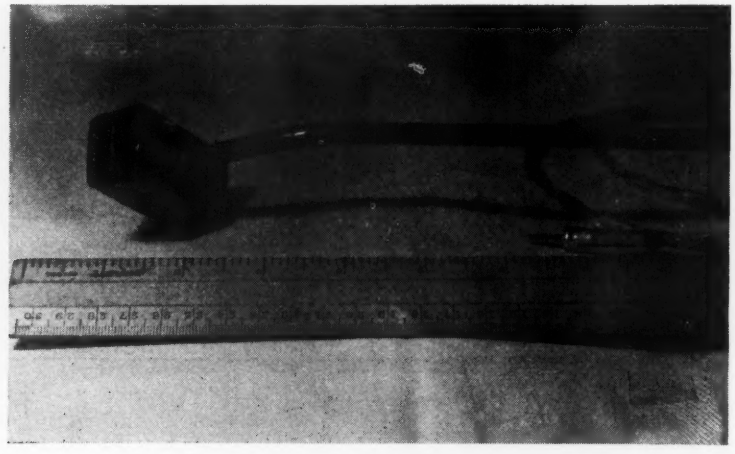

FIG. 2. The source unit.

along a plane surface. In order to produce experimental conditions approximating those called for in the theories, a wax block of dimensions 120 cm×40 cm ×35 cm was held at the bottom of a large tank of water. Most of the experiments were carried out with this block serving as the lower medium; however, some results were obtained with water overlying a concrete block about 3 m×2 m×1 m, and with a light lubricating oil overlying a saturated aqueous solution of calcium chloride contained in a glass tank 125 cm×25 cm×25 cm.

Rochelle salt transducers, of resonant frequency about 100 kcps, were used

to act as the source and detector of elastic energy in the upper medium. The source unit consisted of two rochelle salt 45° *X*-cut bricks, size 5.1 cm×1.9 cm ×0.6 cm, connected in parallel. It was necessary to use such a large unit because the head wave is a second order effect. A photograph of the source unit is shown in Figure 2. The receiver occupied about one quarter the volume of the source, and had an active face of about 1.0 cm×0.3 cm. Because the upper medium was always liquid, it was easy to alter the position of the transducers, and to keep them well away from the outer boundaries of the tank. In order for the transducers to operate at maximum sensitivity, the liquid in which they were immersed was kept at 24°C.

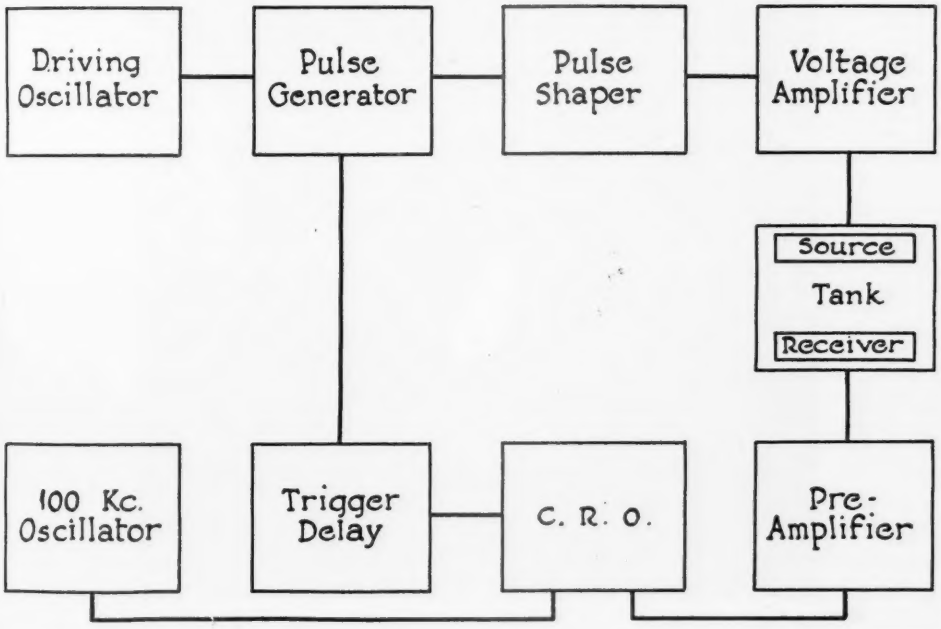


FIG. 3. Block diagram of electronic apparatus.

The experimental set-up and electronic circuitry is very similar in most seismic model studies. The technique used in these experiments was almost identical to that used by Anderson and Northwood (1953) and may be explained by reference to Figure 3. A pulse generator was driven by an audio oscillator and its output fed into the source transducer, via a shaping circuit and voltage amplifier. The shape of the transmitted pulse is a function of the shape of the voltage pulse applied to the transmitting transducer, the characteristics of the transducer, the bonding of the transducer to the medium and the properties of the medium. The shaping circuit was used to exercise some control over the shape of the transmitted pulse by controlling the shape of the applied voltage pulse. The output

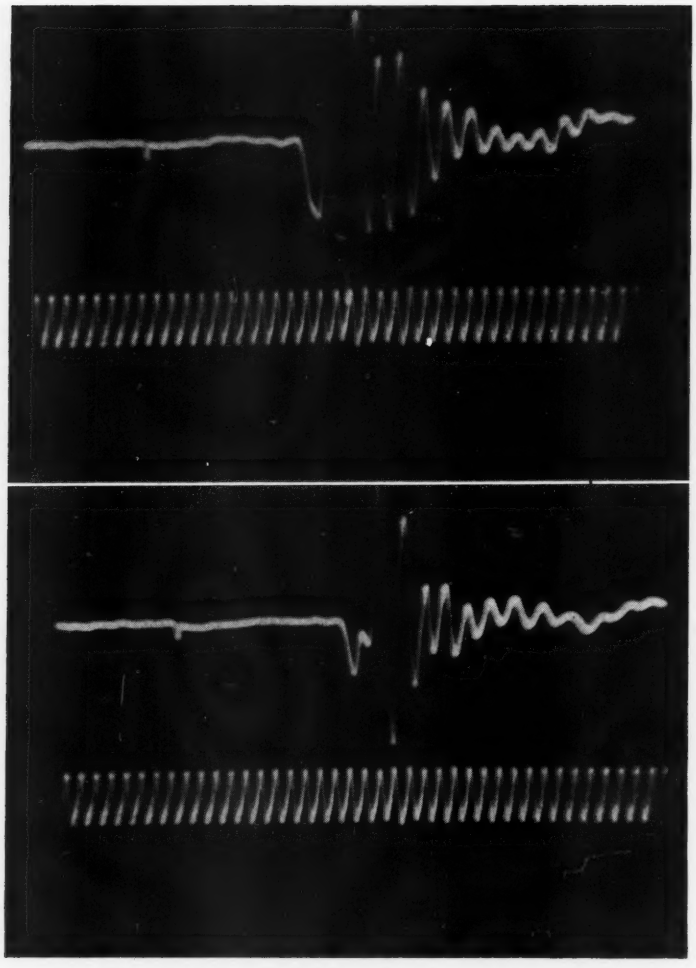

FIG. 4. Photographs of the head wave ($P_1P_2P_1$) and direct pulses for water overlying wax. The upper photograph shows the head-wave and direct pulses completely merged. The lower photograph shows the separation of the first half-cycle of the head-wave pulse. The downward pip on the upper trace is the initiation time of the source.

The lower trace shows the 100-kc timing signal.

of the receiving transducer was fed through a pre-amplifier to the vertical plates of one beam of a split-beam oscilloscope.

A triggering signal of variable delay time was taken from the pulse generator and applied to the synchronizing terminals of the oscilloscope on which one could view a stationary pattern of the received disturbance.

The amplitude of the signal generated by the receiving crystal varied from about 0.5 mv to 0.5 v, and was measured, in arbitrary units, to within about $\pm 5\%$ by means of a graticule superimposed on the screen of the oscilloscope.

To ensure that all elastic reverberations in the medium due to one pulse had ceased before the onset of the next pulse, the repetition rate had to be kept lower than about 60 times per second.

To time the interval between the initial and received pulses the output of a 100-kc crystal oscillator was displayed on the second trace of the oscilloscope, as illustrated in Figure 4. It was possible to measure times to ±one microsecond.

Both the transducers were held in clamps which could be moved along a guide bar graduated in centimeters. It was possible to measure relative distances to ±1 mm, although absolute measurements were only meaningful to ±1 cm, owing to the finite size of the transducer elements.

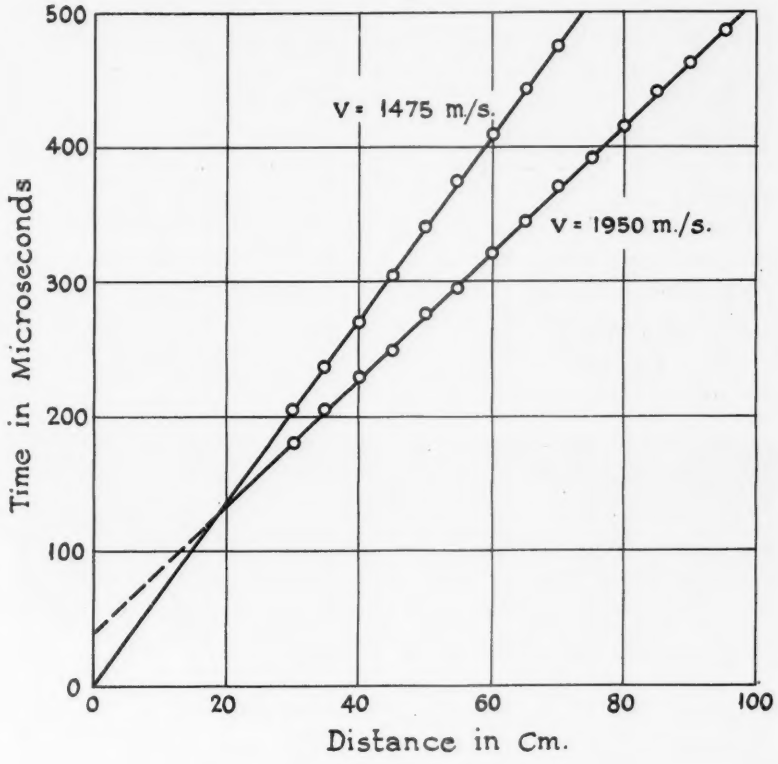


FIG. 5. Time-distance plot for water overlying wax.

## EXPERIMENTAL RESULTS

During the past few years several interesting and important papers on model seismology have been published (e.g., Anderson and Northwood, 1953; Oliver et al., 1953; Evans et al., 1954). One of them (Oliver et al.) was directly concerned with seismic refraction studies. The cases they investigated are more complex

TABLE I

| Medium | Velocity by Direct Measurement | Velocity from Time-Distance Plot |
|---|---|---|
| Calcium chloride solution | 1,850 m/s | 1,850 m/s |
| Wax (dilatational velocity) | 1,950 m/s | 1,950 m/s |
| Concrete (dilatational velocity) | 3,890 m/s | 3,860 m/s |
| Concrete (distortional velocity) | 2,250 m/s | 2,270 m/s |

than the one treated in this paper, for they were interested in head-wave pulses associated with a layer of finite thickness. Previous experimenters on model seismology have been mainly concerned with the recognition and identification of the various "events" on their seismograms. This paper differs from others in presenting quantitative data on the amplitudes of a particular "event"—the head-wave pulse.

Three different parameters were measured: the distance of the source and receiver from the interface and from each other, the time of arrival of the relevant pulse with respect to the initial pulse, and the amplitude of the first half-cycle of the observed pulse.

Two factors render it impossible to make reliable observations on the wave form of the head wave. In the first place, the wave form displayed on the oscilloscope is largely determined by the characteristics of the receiving transducer and amplifying circuits; and, secondly, it was not possible to completely separate the head wave from the subsequent pulses, with the result that it could never be observed in its entirety.

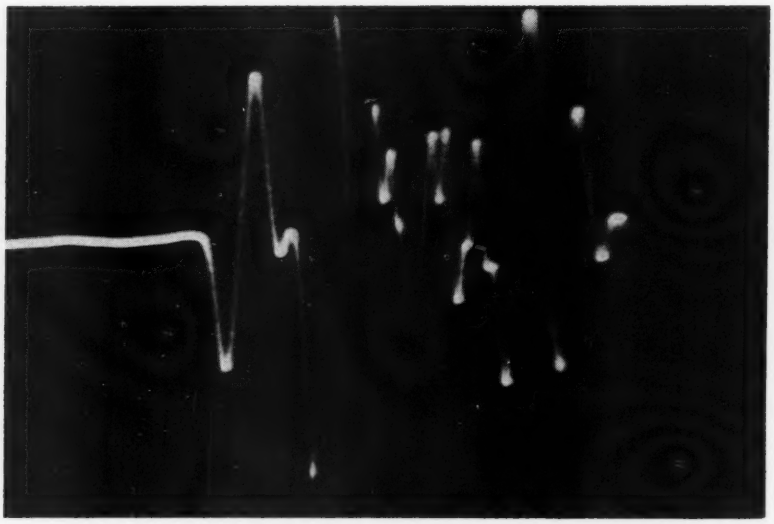

FIG. 6. The head wave ($P_1P_2P_1$) and subsequent pulses for water overlying wax. The direct pulse arrives after about one complete cycle of the head-wave pulse.

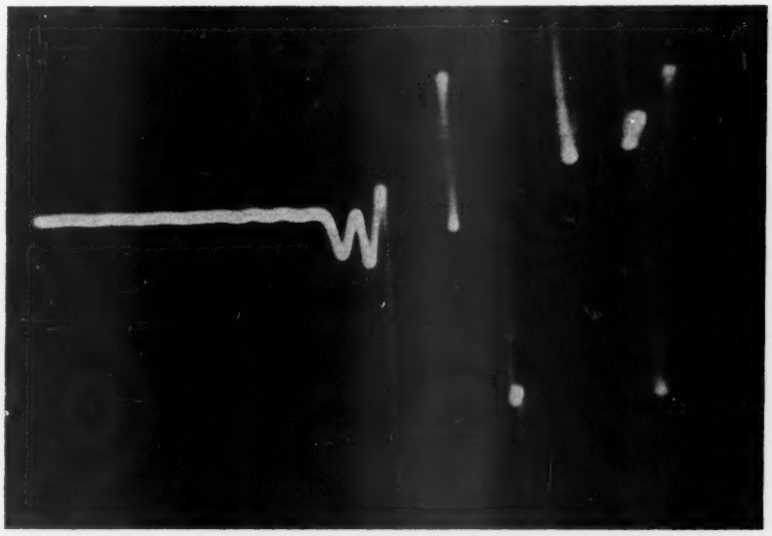

FIG. 7. The head wave and subsequent pulses for oil overlying calcium chloride solution. The onset of the direct pulse is marked by the first strong downward movement of the trace.

Time-distance graphs have been drawn for the three sets of media; a typical one for water overlying wax is shown in Figure 5. As there is nothing novel in head-wave time-distance graphs the others have not been reproduced here. They all show that, within the limits of experimental error, the velocities of the lower medium as found from the head wave agree precisely with those found by direct measurement. A comparison may be seen in Table I. In the case of water overlying wax there is no head wave travelling with the distortional velocity for wax, as this is less than the velocity through water.

It was found that maximum response was obtained when the sensitive face of the receiver was parallel to the front of the head wave. This is in agreement with the theoretical prediction that the displacements in the wave are along the ray path.

In all cases the first movement of the head wave was in the same direction

TABLE II

| Media | Ratio of Amplitudes | Distance between Source and Receiver |
|---|---|---|
| Water/wax | 1:20 | 40 cm |
| Oil/calcium chloride | 1:15 | 42 cm |
| Water/concrete | | |
| $(P_1P_2P_1)$* | 1:100 | 30 cm |
| $(P_1S_2P_1)$ | 1:10 | 30 cm |

* Each letter stands for a segment of a ray path. Dilatational waves are denoted by the letter P, distortional waves by the letter S. The subscript denotes the medium in which the wave travels.

as that of the incident pulse—see for example Figures 6, and 7.

When two liquids were used, it was possible to compare the head wave at points just above the interface with the refracted pulse at points just below the interface. It was found that the times of arrival of the two events were coincident at the boundary, and that their waveforms and amplitudes respectively approached each other as the receiver was moved close to the boundary (Fig. 9).

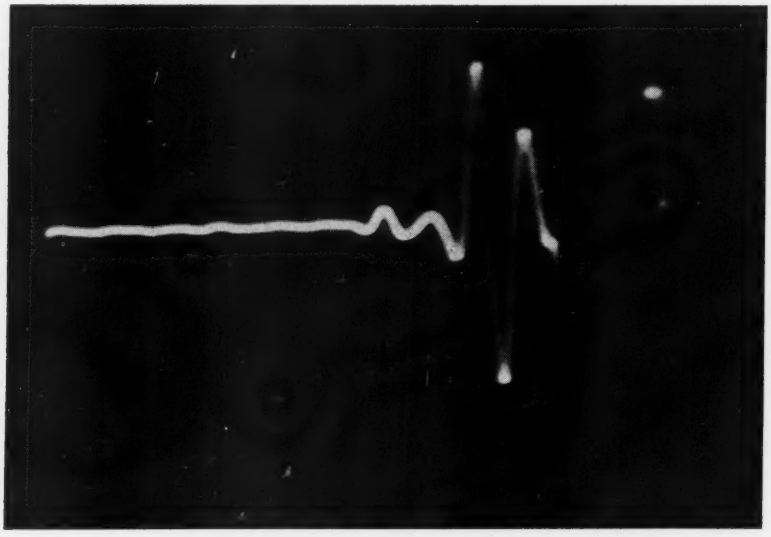

FIG. 8. The two head-wave pulses ($P_1P_2P_1$ and $P_1S_2P_1$) and the direct pulse for water overlying concrete.

The onset of the head wave travelling along the interface with the distortional velocity of concrete occurs after about two cycles of the earlier head wave pulse, which travels with the dilatational velocity. The onset of the direct pulse is given by the strong downward movement of the trace occurring after about one complete cycle of the second head-wave pulse.

## THE AMPLITUDE OF THE HEAD-WAVE PULSE WITH RESPECT TO THE DIRECT PULSE

Along the interface the head wave exists only at points that are farther from the source than the point $A$ in Figure 1. The ratios of the amplitude of the head wave to that of the direct pulse at points close to the interface are given in Table II.

It is interesting to note that in the case of water overlying concrete the wave $P_1S_2P_1$ is considerably stronger than the wave $P_1P_2P_1$. This result would seem to tie in with the fact, already known but perhaps not given sufficient attention, that the velocity for a particular layer obtained by seismic refraction shooting may not agree with those obtained by reflection shooting and by well surveys—even when the layer is thick, homogeneous, and isotropic. More important, this

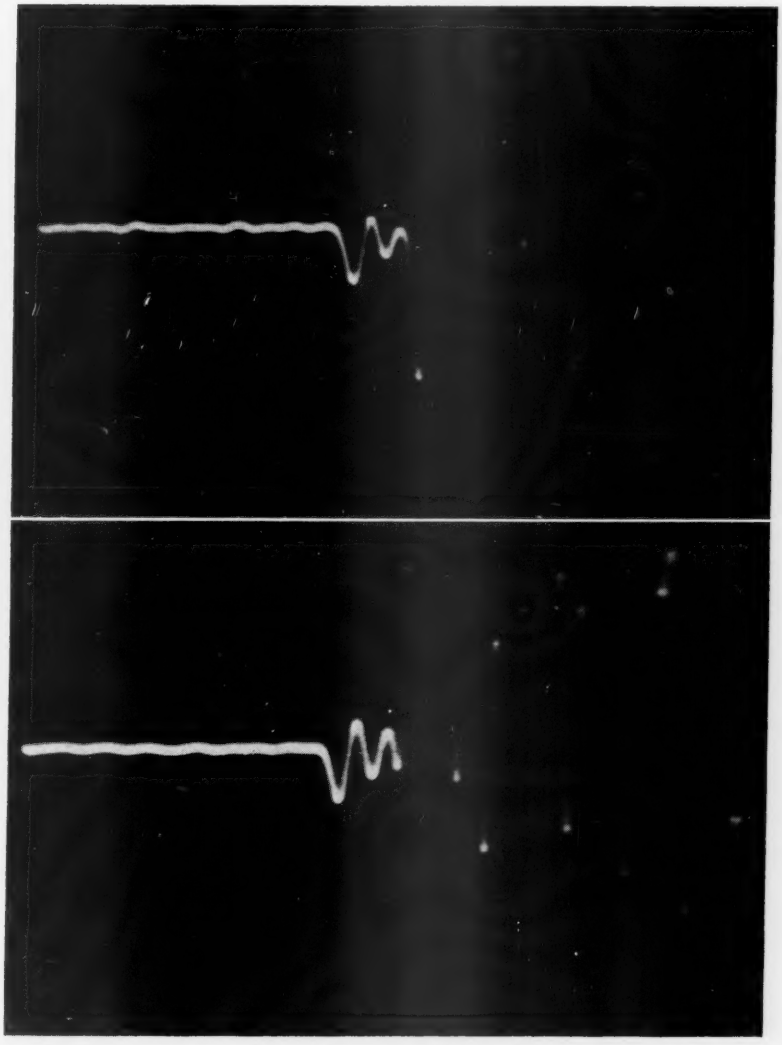

FIG. 9. Upper photograph: the receiver just above a liquid-liquid interface. Lower photograph: the receiver just below a liquid-liquid interface. *Note:* The strong upward movement in the lower photograph is due to a reflection from the bottom of the tank.

velocity may not be the one required in calculating the critical angle and delay time for a ray critically refracted at a deeper interface. An illustration of how this may affect depth determination in refraction shooting is given in the Appendix.

It should be noted that in the photographs reproduced in this paper, the relative amplitudes of the head wave and direct pulses cannot be obtained by simple scaling, because the transducers were oriented to have their direction of maxi-

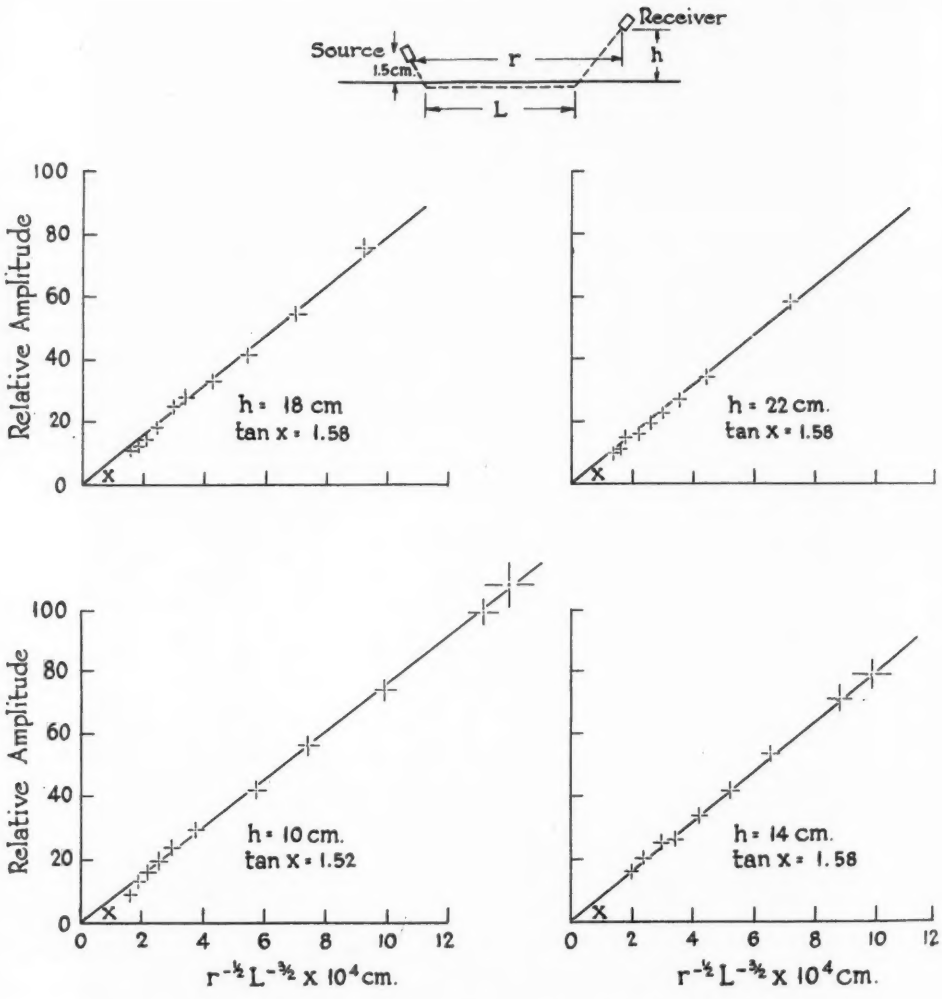


FIG. 10. Decrease of amplitude of the head-wave pulse ($P_1P_2P_1$) along lines parallel to a wax-water interface.

mum sensitivity perpendicular to the front of the head wave.

In order to measure the amplitude of the head wave, it is necessary that sufficient time should elapse for at least its first half-cycle to have been received before the arrival of the direct pulse. This is illustrated in Figure 4, where an amplitude measurement could be made on the lower photograph but not on the upper one. Because of this it was not possible to measure amplitudes at points closer to $A$ than about 10 cm, which, assuming that the predominant frequency in the pulse is equal to the resonant frequency of the transducer, corresponds to four or five wavelengths of the major Fourier component of the pulse.

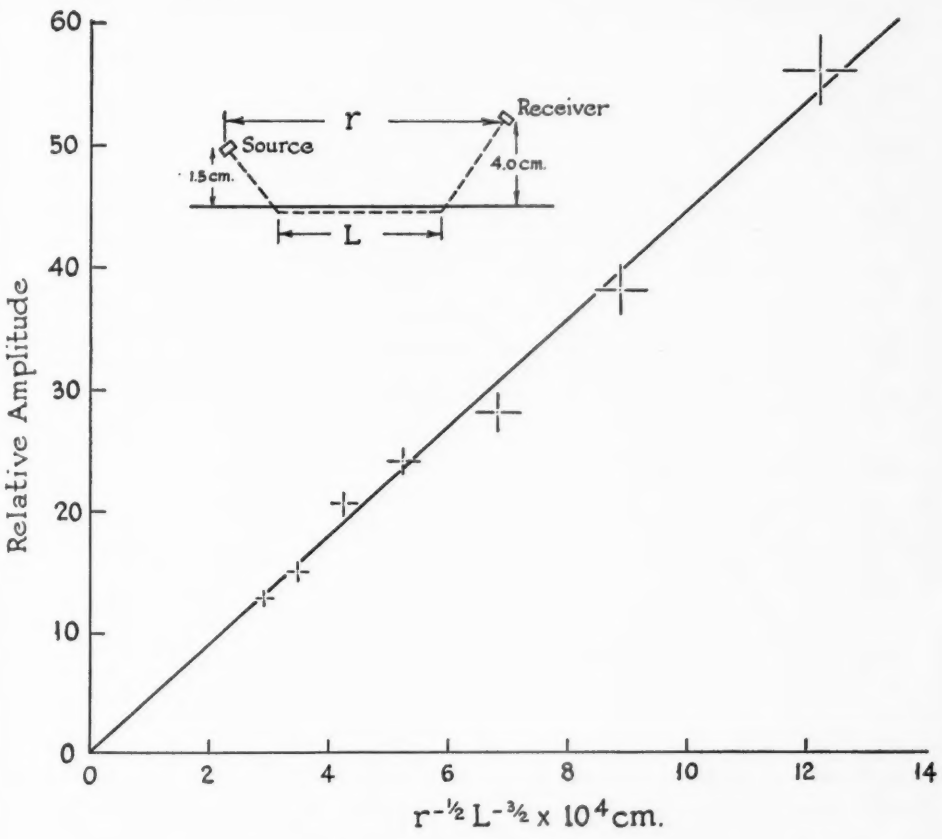


FIG. 11. Decrease of amplitude of the head-wave pulse ($P_1P_2P_1$) along a line parallel to a liquid-liquid interface.

### VARIATION WITH DISTANCE OF THE AMPLITUDE OF THE HEAD WAVE

According to theory, the decrease of amplitude of the head-wave pulse should be given by the equation

$$A = Kr^{-1/2}L^{-3/2}$$

where,

$A$ = amplitude of the head wave,
$K$ = a constant depending upon the source,
$r$, $L$ = distances defined in Figure 1.

Measurements of amplitudes were made along lines parallel and along lines perpendicular to the interface. In the resulting graphs, Figures 9 to 12, the horizontal and vertical lines forming a cross at each point give an estimate of the maximum observational error in the measurements of the two variables, distance

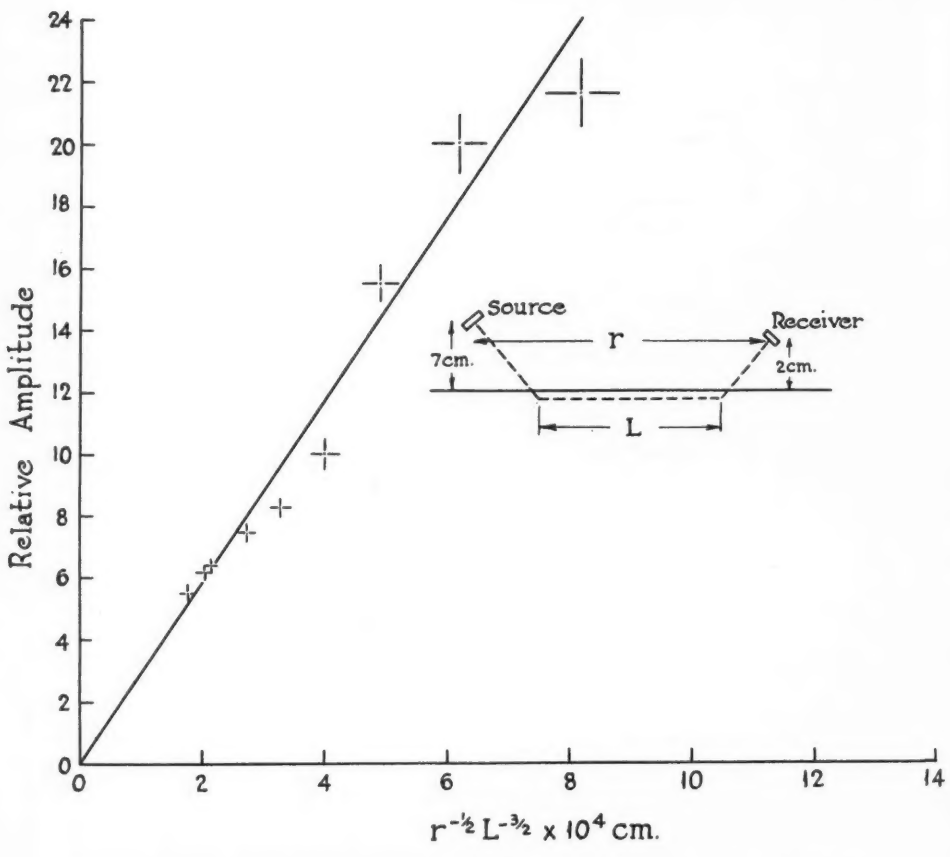


FIG. 12. Decrease of amplitude of a head-wave pulse ($P_1S_2P_1$) along a line parallel to a water-concrete interface.

and amplitude. They do not indicate the total experimental error, which includes other factors not easily estimated, such as mis-orientation of the transducers, inhomogeneities of the media, etc.

### VARIATION OF AMPLITUDE ALONG A LINE PARALLEL TO THE INTERFACE

Figures 10, 11, and 12 show the amplitude of the head wave plotted against the factor $r^{-1/2}L^{-3/2}$. As required by theory, straight lines were drawn through the points and through the origin—as obviously the amplitude should be zero at infinity. The scatter about the lines is considered to be within the total experimental error; thus these data agree with the theory.

In Figure 10, four sets of data are plotted, each for a different height $h$ of the receiver above the interface, all the other conditions being identical. It may be seen that the gradients of the lines, given by tan $X$ in the figure, agree to within 5 percent. This shows further agreement with the theory.

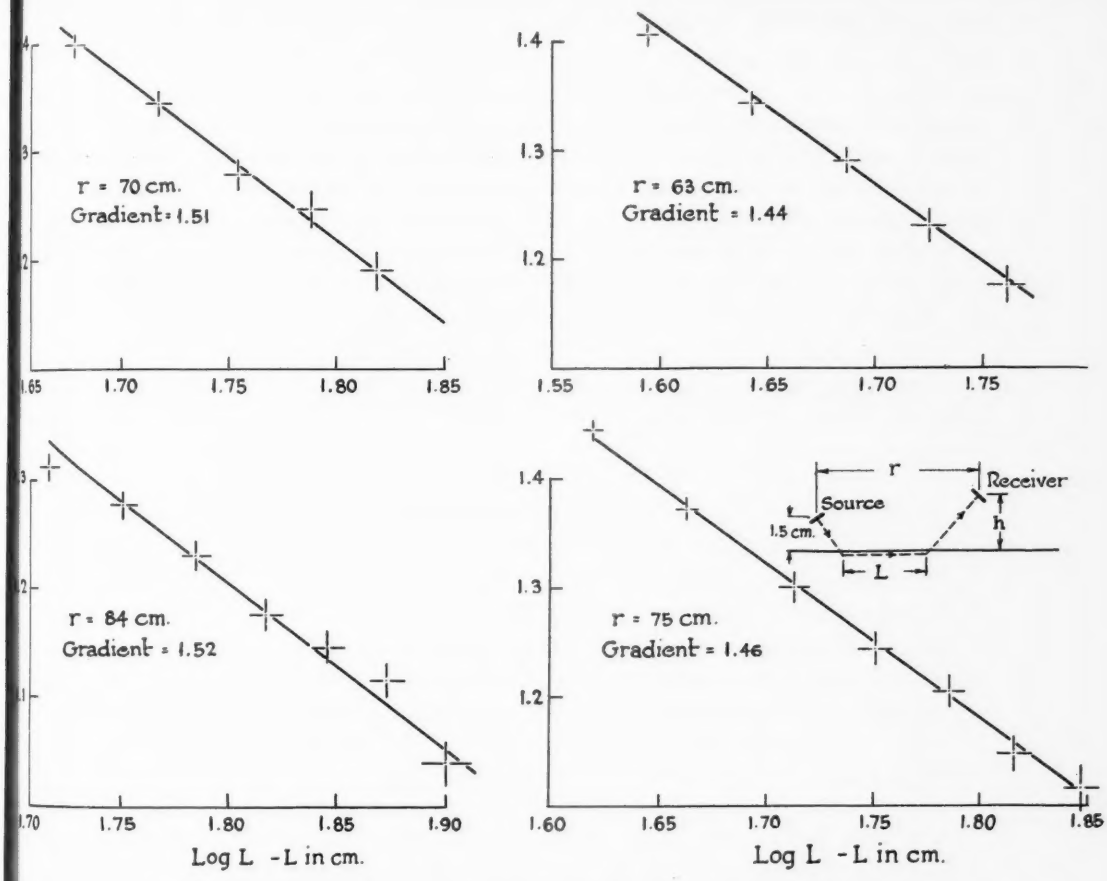


FIG. 13. Plot showing decrease of amplitude of the head-wave pulse ($P_1P_2P_1$) along lines perpendicular to wax-water interface.

In Figure 12, which is a plot for water overlying concrete, the scatter in the points is greater than in the corresponding plots for water overlying wax and for oil overlying calcium chloride solution. This is mainly because the observations were made on the pulse which travelled along the interface with the distortional wave velocity. This pulse coincides in time with the tail of the earlier pulse which travelled along the interface with the dilatational wave velocity; the reliability of the amplitude measurements is thus decreased. Inhomogeneities in the concrete may also account for some of the scatter in the points, although in mixing and pouring the concrete special care was exercised to obtain a fine, homogeneous mixture.

### VARIATION OF AMPLITUDE ALONG A LINE PERPENDICULAR TO THE INTERFACE

Four sets of data were obtained with the receiver set at different cylindrical

distances $r$ (see Fig. 1) from the source, all other conditions remaining constant. By varying the height $h$ of the receiver above the interface, while keeping $r$ constant, the detected head wave must follow a ray path whose distance $L$ along the interface decreases as $h$ increases. Figure 13 shows the logarithm of the relative amplitude plotted against the logarithm of $L$; straight lines have been drawn through the points. As $r$ is constant for each set of data, these lines should have a gradient of $-1.50$; in fact, their gradients vary from $-1.44$ to $-1.52$, averaging $-1.49$. The experimental data are certainly not sufficiently reliable to attach any significance to this difference between the arithmetical average of the experimental gradients and their theoretical value.

Further, if $A$ is the intercept on the log $L$ axis and the amplitude really does vary as $r^{-1/2}L^{-3/2}$, then $3A/2+(\log r)/2$ should be constant. The data show that this is so to within 5 percent.

## SUMMARY AND CONCLUSIONS

Head waves were observed with three different pairs of media: oil overlying calcium chloride solution, water overlying wax, and water overlying concrete. In the first pair no distortional wave is possible and the observed head wave travelled along the interface with the dilational velocity of the lower medium. In the second pair the distortional velocity in wax is less than the velocity through water and no head wave was observed which travelled with the distortional velocity through wax. In the third pair, both the dilatational and distortional velocities through concrete are greater than the velocity through water and head waves travelling with both velocities were observed.

Quantitative measurements were made on the amplitude of the head wave and, within the experimental error, the data agree with the predictions of Cagniard and others that the decrease with distance should be proportional to $r^{-1/2}L^{-3/2}$, where $r$ is the orthogonal projection on the interface between the source and detector and $L$ is the distance the wave has travelled in the lower medium.

## ACKNOWLEDGMENTS

This work is part of a doctoral thesis written at the University of Toronto. Financial assistance from the National Research Council of Canada is gratefully acknowledged.

## APPENDIX

In the laboratory experiments reported above, it is shown that for water overlying concrete, the head-wave pulse travelling along the boundary with the $S$-wave velocity of the lower medium has much greater energy than the head wave pulse travelling with the $P$-wave velocity. If this should occur in exploration refraction shooting, then the head wave travelling with the $P$-wave velocity might be missed, especially if secondary arrivals are being used, and consequently the thickness of the layer might be erroneously calculated.

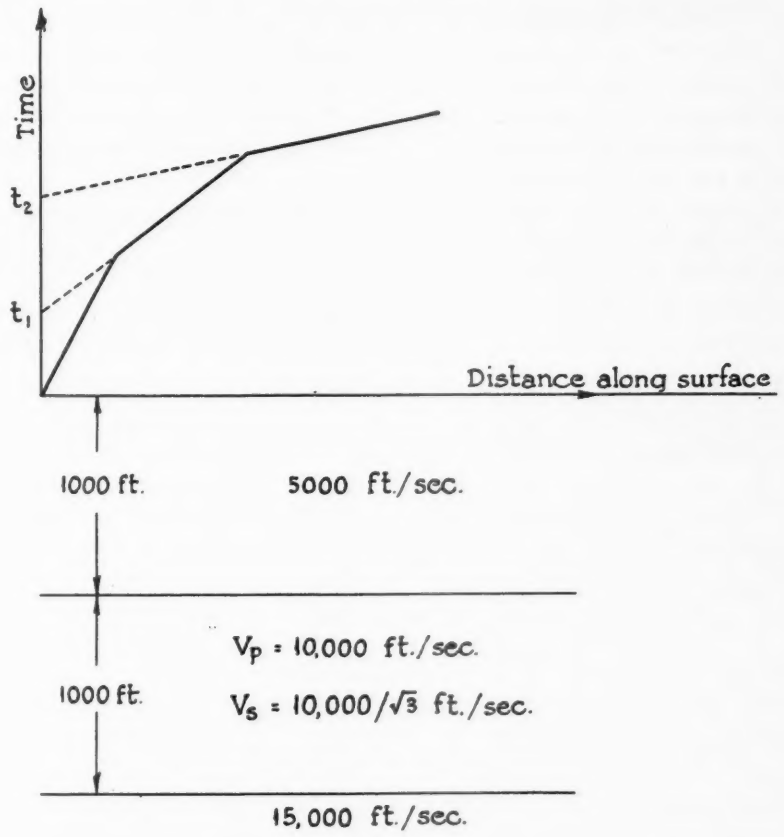


FIG. 14. A hypothetical three-layer case.

The following simple example may serve as an illustration of how such an error could result.

Consider the section drawn in Figure 14. Two successive layers, each of thickness one thousand feet, rest on top of another layer. The uppermost layer has a *P*-wave velocity of 5,000 feet per second, the second layer a *P*-wave velocity of 10,000 feet per second, and the third layer a velocity of 15,000 feet per second. A refraction time-distance graph for such a section would consist of three straight lines, as shown in the figure.

If the arrivals recorded have travelled the whole of their paths as *P* waves, then the gradients of the lines would be 0.00020 sec/ft, 0.00010 sec/ft, and 0.000067 sec/ft. The intercept times $t_1$ and $t_2$ would be 0.346 sec and 0.526 sec respectively.

Now suppose that the first critically refracted wave had travelled along the interface with the *S*-wave velocity. Assuming that Poisson's ratio for the middle layer was 0.25, the gradient of the second limb of the time-distance graph would

be 0.00017 sec/ft. If the wave critically refracted at the lower boundary travels through the second layer as an $S$-wave, $t_2$ would also change and no error in thickness would result. However, if this second critically refracted wave had travelled down to the second boundary as a $P$-wave, then calculation of depth would be made using the irrelevant $S$-wave velocity $10{,}000/\sqrt{3}$ ft/sec, instead of the $P$-wave velocity 10,000 ft/sec.

In this latter case the intercept times will be 0.200 sec and 0.526 sec. The thickness of the first layer will, of course, be calculated correctly, but that of the second layer will be calculated as 466 feet, and an error of 534 feet will result.

It would be interesting if data were available on the division of head wave energy between the $P_1P_2P_1$ and $P_1S_2P_1$ phases for actual geologic boundaries.

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GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955), PP. 243–253, 4 FIGS.

# PROBABILITY DISTRIBUTION OF REFLECTIONS ON SEISMIC RECORDS*

LUCIEN MASSÉ†

ABSTRACT

A modification of the theory of radar information is proposed for the analysis of noisy seismic records by means of the cross-correlation function. The method is applied to a synthetic record, and the amount of information provided by the method is evaluated by means of Shannon's formula.

## INTRODUCTION

One of the early steps encountered in the course of processing seismic records is the "picking" of reflections. Although this operation is theoretically well defined, in practice it turns out to be a statistical decision problem of detection and of time measurement.

Radar ranging is essentially a similar problem which has been studied extensively in the light of Shannon's information theory and of Wiener's prediction theory. One common feature of all recent investigations relevant to the above theories is the widespread use of statistical methods to extract information from mixtures of meaningful signals and random noise.

One characteristic of the radar problem has contributed materially in providing a satisfactory solution: a sample of the signal is available at all times for comparison with the input to the receiver. This circumstance, which has made correlation reception possible in the case of radar, is entirely lacking in the seismic problem. Nevertheless, it is possible to use correlation methods in the treatment of seismic data; recent papers in GEOPHYSICS have brought out this point.

This paper presents a heuristic account of some results obtained by Woodward and Davies in their study of radar reception and an application of these results to the analysis of part of a seismic record.

## OUTLINE OF THE THEORY

The process of picking reflections on a seismic record is essentially that of detection of signals in the presence of noise when the signal-to-noise ratio is rather low. Several methods of accomplishing this have been suggested which involve the use of cross-correlation as a pre-detection filtering device so that the detection of reflections in the filtered output is somewhat easier than in the input to the filter.

Woodward and Davies (1950) have attempted the evaluation of the probability distribution associated with the detection of radar signals. Starting from a given prior probability, they compute the posterior probability of the existence

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of signals in noise after study of the receiver output. With slight modifications, this method can be applied to the analysis of seismic records.

Given a noisy section of a seismic record, the problem is to decide whether it contains a reflection signal and, if so, where it is located on the time scale. We assume in the following analysis that there is one and only one reflection in the time section under consideration. This assumption will be relaxed later.

We propose to compute the probability distribution of reflections in this time section. In other words, we wish to plot a curve as a function of time giving the probability that there exists a reflection on the record at any given time.

The usual frequency interpretation of probability which expresses this concept as a ratio will not quite serve our purpose since we have no convenient way of evaluating such a frequency ratio. Instead, we will adopt Jeffreys' outlook on probability as the degree of belief or of confidence we have in the truth of any given proposition on the basis of the data available to us. We will then speak of the probability of a proposition $q$ on the basis of data $H$ and write $P(q/H)$ for the number associated with this probability.

In the discussion that follows we shall consider $q_r$ to be the proposition: "The reflection (postulated above) occurs at time $t_r$." The data $H$ on which the probability of $q_r$ is evaluated will be the whole of the seismic data available to us either as deductions from seismic theory or as information previously obtained in the area concerned.

The central idea of the method consists in an application of the inverse probability theorem (Bayes' theorem) which Jeffreys (1948, p. 28–29) proves in the form

$$P(q_r/pH) = \frac{1}{P(p/H)} \cdot P(q_r/H) \cdot P(p/q_rH) \tag{1}$$

where $q_r$ and $H$ will have the meaning defined above and $p$ is some additional data. $P(q_r/H)$, being the probability of $q_r$ on data $H$ alone, is called the prior probability, while $P(q_r/pH)$ is the posterior probability of $q_r$ on data $p$ and $H$. $P(p/q_rH)$ is the likelihood introduced by Fisher.

In our analysis of seismic records we shall use the following definitions.

$P_i$ is the data provided by the record trace of rank $i$ in a set of $m$ traces;

$P_{r0} = P(q_r/H)$ at the beginning of the analysis, i.e., the prior probability before studying the record;

$P_{r1} = P(q_r/p_1H)$ is the posterior probability of $q_r$ after analyzing trace 1;

$L_{r1} = P(p_1/q_rH)$ is the likelihood associated with trace 1 at time $t_r$. As a whole, the likelihood associated with trace 1 is the probability of actually recording the observed trace 1 given a reflection at time $t_r$.

We can then write equation (1) for trace 1 as follows:

$$P_{r1} = k_1 P_{r0} L_{r1} \tag{2}$$

where $k_1$ is a constant in that it does not depend on $q_r$ but only on $p_1$ and $H$.

If the record is analyzed systematically trace by trace, then it is clear that $P_{r1}$, the posterior probability after the analysis of trace 1, becomes the prior probability before the analysis of trace 2, so that

$$P_{r2} = k_2 P_{r1} L_{r2} = k_1 k_2 P_{r0} L_{r1} L_{r2}$$

and in general

$$P_{ri} = k_i P_{r(i-1)} L_{ri} \tag{3}$$

and

$$P_{rm} = k P_{r0} \prod_{i=1}^{i=m} L_{ri}. \tag{4}$$

The above scheme shows that the probability of $q_r$ is modified by the analysis of any trace on the record and that the posterior probability can be determined if both the prior probability and the likelihood are known.

The choice of the prior probability $P_{r0}$ is somewhat arbitrary. In fact, we can even suppose that we know nothing that will induce us to prefer any particular alternative $q_r$. In this case, we adopt a uniform distribution for $P_{r0}$; i.e., we assume that $P_{r0}$ does not depend on $r$. Successive applications of equation (3) as indicated by equation (4) will lead to an estimation of $P_{rm}$ after all the traces of the record have been analyzed.

As each trace is analyzed in turn, the posterior probability $P_{ri}$ will be seen to converge stochastically towards its final value $P_{rm}$. The rate of convergence is influenced by the quality of the record which is reflected in each likelihood $L_{ri}$ and also by the choice of the prior probability $P_{r0}$.

The usual postulates and conventions of probability theory require that the numbers associated with probabilities be restricted to real numbers in the range $0 \leqq P \leqq 1$. Hence, writing

$$L_{ri} = CG_i(t_r), \tag{5}$$

where $C$ is a normalizing constant, the function $G_i(t_r)$ must be non-negative for all values of $t_r$. Since $L_{ri}$ is the probability of recording trace $i$ on data $H$ given a reflection at time $t_r$, then the values of $G_i(t_r)$ must be ordered according to the degree of our belief in the above proposition. Any function that satisfies these two conditions can be substituted for $G_i(t_r)$.

It is well known that the cross-correlation function

$$\phi_i(t_r) = \int_A^B F(\tau) f_i(\tau - t_r) d\tau \tag{6}$$

expresses the degree of similarity or coherence between the two functions $F(t)$ and $f(t)$ in the interval $AB$, so that the ordering condition mentioned above is satisfied by this function. However $\phi_i(t_r)$ can be positive or negative depending

on the functions $F(t)$ and $f(t)$ so that it is not immediately available for substitution in (5).

We note that $\exp(\phi_i(t_r))$ is never negative and, since it is monotone increasing, it preserves the ordering of $\phi_i(t_r)$ so that it fully satisfies the conditions on $G_i(t_r)$.

We must now decide on the selection of $F(t)$ and $f(t)$. Since we are attempting to analyze individual traces on seismic records, we shall choose $f_i(t_r)$ to represent the recorded trace of rank $i$. We shall select for $F(t)$ some suitable wave form representing a reflected pulse such as a Ricker wavelet. The exponential of the cross-correlation function will then yield a positive real number for each value of $t_r$ which will be a monotone function of the degree of coherence between the two functions.

Replacing the cross-correlation function by its exponential presents a further advantage. Since the data provided by trace $i$ contribute nothing to the prior probability at stage $i$, it is clear that all the information contained in trace $i$ and capable of modifying the posterior probability must be found in the likelihood function. If, then, we expect to learn much that is new, the likelihood must vary much more with $r$ than does the prior probability. The exponential function provides this increase in the range of variation very effectively.

The trace of rank $i$ can be represented by

$$f_i(t_r) = s_i(t_r) + n_i(t_r), \tag{7}$$

where $s_i$ and $n_i$ are respectively the signal and noise that make up the recorded trace. It is reasonable to expect that the greater the signal-to-noise ratio, the less difficulty will be experienced in the decision process. The amplitude and shape of the signal wave form are taken into account in the cross-correlation function. The hindering effect of noise can be introduced by dividing the cross-correlation function by $N/2$, where $N$ is the energy of the noise spectrum per unit bandwidth. This produces the desired effect of decreasing the likelihood function when the noise level is high. Thus we obtain finally

$$L_{ri} = C \exp\left(\frac{2}{N}\phi_i(t_r)\right). \tag{8}$$

Thus turns out to be the likelihood function associated with a Gaussian distribution of noise.

The value assigned to $N$ is not critical. A workable value can be obtained by computing the average of $n_i^2/2W$ where $W$ is the highest recorded frequency over portions of the record traces which are unlikely to contain any signal. The effect of selecting a value of $N$ that is much too large will be to equalize the posterior probabilities so that little information is gained in the process.

Since we have originally assumed one and only one reflection in the interval considered, say $AB$, then we must have

$$\int_A^B P_{ri}(t_r)dt_r = 1. \tag{9}$$

If the reflection occurs at a time $t_r = t_a$, then, as the number of traces increases,

$$\lim_{m\to\infty} P_{rm} = \delta(t_r - t_a), \tag{10}$$

where $\delta(t)$ is Dirac's delta measure. Equation (10) holds strictly only in case the noise has a random distribution.

The integration indicated in equation (6) can be carried out by means of a suitable analog computer. It is also easy to do on digital computers since Shannon's sampling theorem provides a convenient means of introducing a discrete system.

According to the sampling theorem, if the highest frequency present in $f_i(t_r)$ is $W$ cps then the function is completely described if it is given at time intervals of $\frac{1}{2}W$ second. Inversely, specifying a function by values given at intervals of $\frac{1}{2}W$ sec effectively destroys all frequency components higher than $W$ cps. Hence, assuming that a seismic record contains no component of frequency higher than 100 cps, the sampling can be done every 0.005 sec.

In this case, the integral of equation (6) is replaced by a finite sum and equation (9) becomes

$$\sum_{r=1}^{n} P_{ri} = 1. \tag{11}$$

Equation (10) can be written

$$\lim_{m\to\infty} P_{rm} = \begin{cases} 1 & \text{if } t_r = t_a \\ 0 & \text{if } t_r \neq t_a. \end{cases} \tag{12}$$

Equations (10) and (12) show that if a reflection exists at time $t_a$, then the probability distribution function should gradually develop a peak at $t_a$ as the number of the traces analyzed increases.

In case there is no reflection in the interval analyzed, the probability function will develop some broad peaks in the initial stages but will gradually decrease and finally disappear so that a uniform distribution is obtained. This of course supposes that a sufficient number of traces is available for analysis and that the noise has a random distribution.

If, on the other hand, there are $K$ reflections in the interval under consideration, then $K$ peaks will develop, although generally they will vary greatly in size. In order to bring out the weak ones, the amplitude of each peak can be limited to $1/K$.

It is clear that other forms of the function $G_i(t_r)$ can be found, some of which may accelerate the convergence of the iteration process in the case of seismic records. The preceding analysis has assumed that all reflections have the same sign. Modifications in the procedure to accommodate reversals are obvious. The same applies to records with substantial step-out and dips.

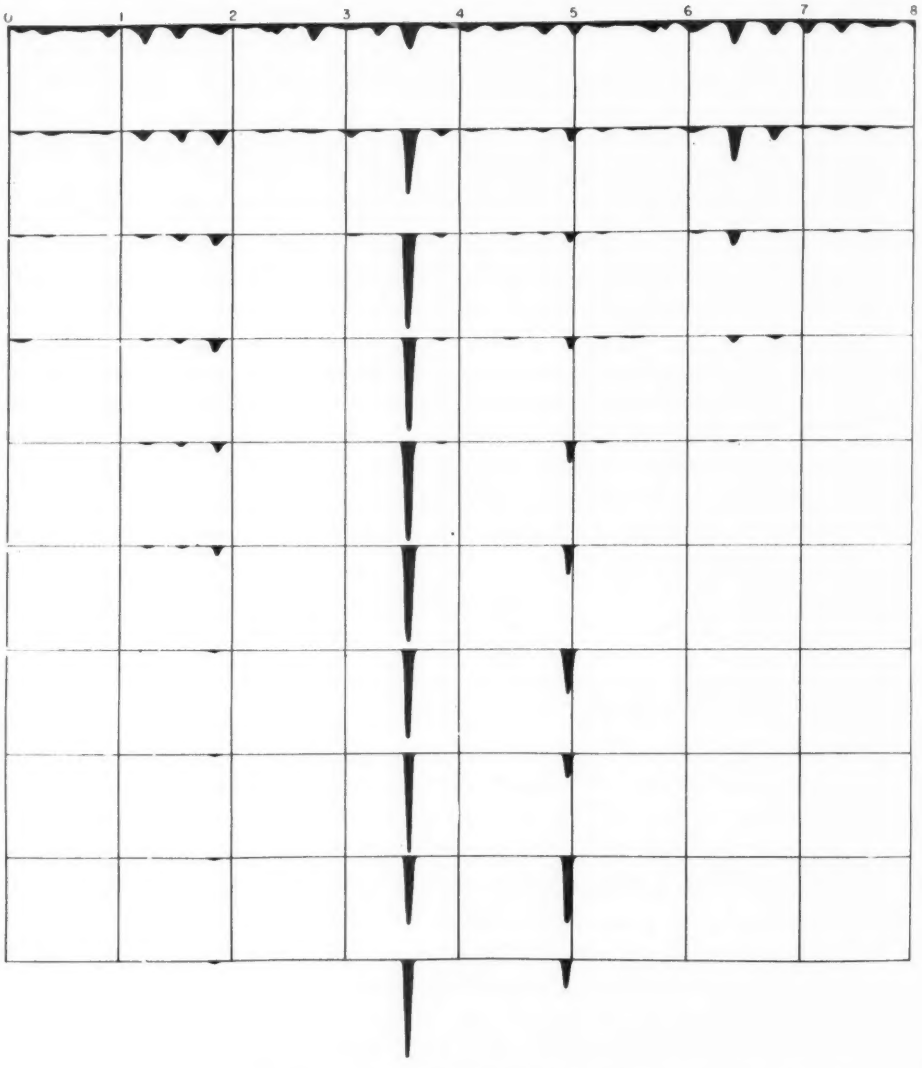


FIG. 1. Probability distribution of reflections on synthetic seismic record. The probabilities are plotted on an arc sine scale to emphasize low values.

## TEST OF THE METHOD

The method described above was tried on a synthetic record published by Dyk and Eisler (1951, Figure 3, p. 453). Only part of this record was analyzed. The second 0.1-sec marker was taken as $t=0$ and reflections were sought in the following 0.8 sec.

This record was obtained artificially by superimposing a number of well-determined reflections on a background of nearly random noise, for the specific

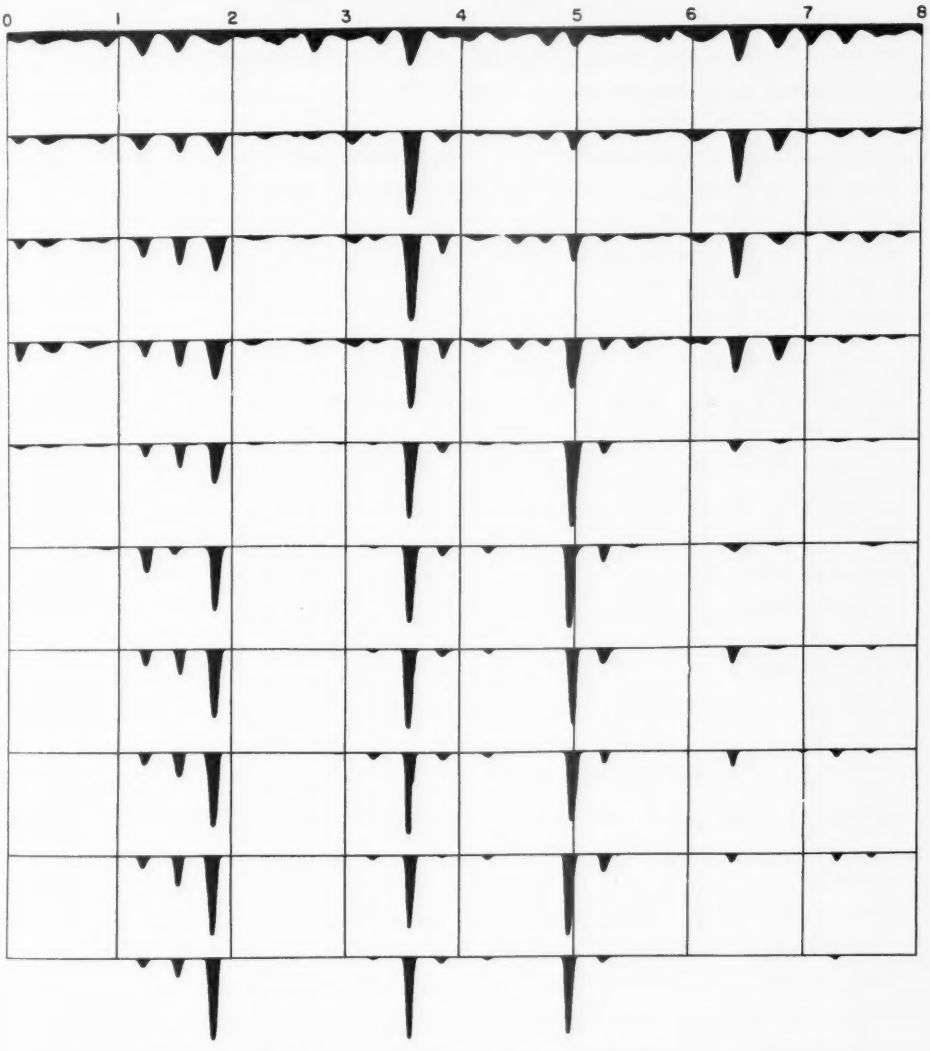


FIG. 2. Probability distributions as in Figure 1 but normalized on the assumption of three actual reflections.

purpose of studying the effect of noise on the picking of reflections. Ten synthetic traces were available for analysis and the signal alone was recorded on a separate trace. The function $F(t)$ was obtained from the first reflection recorded on this trace and the probability functions were computed at intervals of 0.005 sec, starting from a uniform probability distribution.

The resulting probability functions are plotted in Figure 1, where the top scale gives the time in tenths of a second. The scale of probabilities was chosen so that the interval between the reference lines for consecutive traces corresponds

to a probability of one. This representation shows clearly the gradual decrease of the random noise and the relative quality of the three reflections present. The probabilities were computed and plotted in the order in which the traces appear on the record, from top to bottom.

Since it soon became apparent that there were probably three reflections in the interval chosen, the probabilities were recomputed after limiting each individual peak to one-third. The results are plotted in Figure 2, where the vertical scale has been changed to one-third. The immediate result is to equalize the probabilities of the three reflections and increase somewhat the effect of the noise (which does not appear to be completely random).

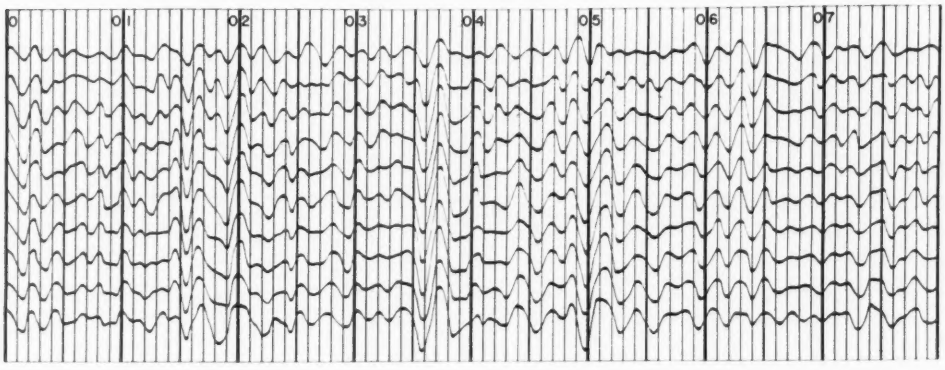


FIG. 3. Result of mixing original record. The trace of rank $i$ from the top was obtained by adding the first $i$ traces of the original record.

It must be pointed out that the probabilities in both Figures 1 and 2 are not plotted on a linear scale. An arc sine scale was used to emphasize the small values. A linear scale would have brought out more clearly the contrast between the amplitude of the reflections and of the background noise. To show this, the probability values for the tenth trace of Figure 2 are given in Table I.

Figure 3 shows the result obtained by completely mixing the original record. The first trace in Figure 3 is identical with the first trace on the record. The second trace on Figure 3 is the sum of the first two traces on the record, and so on, so that the bottom trace in Figure 3 is the sum of all the traces on the record. This mixing process shows that the noise is not completely random (at least in this small sample). The contrast between the reflections and the noise is much less in Figure 3 than in the case of the probability curves of Figures 1 and 2.

Various modifications and refinements are possible to increase the efficiency of the method; among them are: proper choices of the comparison signal, the prior probability, and the form of the likelihood function.

A comparison of equations (4), (6), and (8) shows that

$$P_{rm} = kP_{r0}\prod_{i=1}^{m} \exp \phi_i(t_r)$$

$$= kP_{\tau 0} \exp \sum_{i=1}^{m} \phi_i(t_\tau)$$

where

$$\sum_{i=1}^{m} \phi_i(t_\tau) = \sum_{i=1}^{m} \int_A^B F(\tau) f_i(\tau - t_\tau) d\tau = \int_A^B F(\tau) \sum_{i=1}^{m} f_i(\tau - t_\tau) d\tau,$$

so that the last trace of Figures 1 and 2 could have been obtained directly from

TABLE I

MODIFIED PROBABILITY DISTRIBUTION FOR TENTH TRACE OF FIGURE 2

| $t$ | $P$ | $t$ | $P$ | $t$ | $P$ | $t$ | $P$ |
|---|---|---|---|---|---|---|---|
| 0.000 | 0.0000 | 0.200 | 0.0000 | 0.400 | 0.0000 | 0.600 | 0.0000 |
| 0.005 | 0.0000 | 0.205 | 0.0000 | 0.405 | 0.0000 | 0.605 | 0.0000 |
| 0.010 | 0.0000 | 0.210 | 0.0000 | 0.410 | 0.0000 | 0.610 | 0.0000 |
| 0.015 | 0.0000 | 0.215 | 0.0000 | 0.415 | 0.0000 | 0.615 | 0.0000 |
| 0.020 | 0.0000 | 0.220 | 0.0000 | 0.420 | 0.0000 | 0.620 | 0.0000 |
| 0.025 | 0.0000 | 0.225 | 0.0000 | 0.425 | 0.0007 | 0.625 | 0.0000 |
| 0.030 | 0.0000 | 0.230 | 0.0000 | 0.430 | 0.0000 | 0.630 | 0.0000 |
| 0.035 | 0.0000 | 0.235 | 0.0000 | 0.435 | 0.0000 | 0.635 | 0.0001 |
| 0.040 | 0.0000 | 0.240 | 0.0000 | 0.440 | 0.0000 | 0.640 | 0.0000 |
| 0.045 | 0.0000 | 0.245 | 0.0000 | 0.445 | 0.0000 | 0.645 | 0.0000 |
| 0.050 | 0.0000 | 0.250 | 0.0000 | 0.450 | 0.0000 | 0.650 | 0.0000 |
| 0.055 | 0.0000 | 0.255 | 0.0000 | 0.455 | 0.0000 | 0.655 | 0.0000 |
| 0.060 | 0.0000 | 0.260 | 0.0000 | 0.460 | 0.0000 | 0.660 | 0.0000 |
| 0.065 | 0.0000 | 0.265 | 0.0000 | 0.465 | 0.0000 | 0.665 | 0.0000 |
| 0.070 | 0.0000 | 0.270 | 0.0000 | 0.470 | 0.0000 | 0.670 | 0.0000 |
| 0.075 | 0.0000 | 0.275 | 0.0000 | 0.475 | 0.0000 | 0.675 | 0.0000 |
| 0.080 | 0.0000 | 0.280 | 0.0000 | 0.480 | 0.0000 | 0.680 | 0.0000 |
| 0.085 | 0.0000 | 0.285 | 0.0000 | 0.485 | 0.0000 | 0.685 | 0.0000 |
| 0.090 | 0.0000 | 0.290 | 0.0000 | 0.490 | 0.0000 | 0.690 | 0.0000 |
| 0.095 | 0.0000 | 0.295 | 0.0000 | 0.495 | 0.2892 | 0.695 | 0.0000 |
| 0.100 | 0.0000 | 0.300 | 0.0000 | 0.500 | 0.0108 | 0.700 | 0.0000 |
| 0.105 | 0.0000 | 0.305 | 0.0000 | 0.505 | 0.0000 | 0.705 | 0.0000 |
| 0.110 | 0.0000 | 0.310 | 0.0000 | 0.510 | 0.0000 | 0.710 | 0.0000 |
| 0.115 | 0.0000 | 0.315 | 0.0000 | 0.515 | 0.0000 | 0.715 | 0.0000 |
| 0.120 | 0.0012 | 0.320 | 0.0000 | 0.520 | 0.0000 | 0.720 | 0.0000 |
| 0.125 | 0.0025 | 0.325 | 0.0007 | 0.525 | 0.0018 | 0.725 | 0.0006 |
| 0.130 | 0.0000 | 0.330 | 0.0002 | 0.530 | 0.0003 | 0.730 | 0.0011 |
| 0.135 | 0.0000 | 0.335 | 0.0000 | 0.535 | 0.0000 | 0.735 | 0.0000 |
| 0.140 | 0.0000 | 0.340 | 0.0000 | 0.540 | 0.0000 | 0.740 | 0.0000 |
| 0.145 | 0.0000 | 0.345 | 0.0000 | 0.545 | 0.0000 | 0.745 | 0.0000 |
| 0.150 | 0.0044 | 0.350 | 0.0000 | 0.550 | 0.0000 | 0.750 | 0.0000 |
| 0.155 | 0.0164 | 0.355 | 0.3103 | 0.555 | 0.0007 | 0.755 | 0.0000 |
| 0.160 | 0.0000 | 0.360 | 0.0230 | 0.560 | 0.0002 | 0.760 | 0.0004 |
| 0.165 | 0.0000 | 0.365 | 0.0000 | 0.656 | 0.0000 | 0.765 | 0.0000 |
| 0.170 | 0.0000 | 0.370 | 0.0000 | 0.570 | 0.0000 | 0.770 | 0.0000 |
| 0.175 | 0.0000 | 0.375 | 0.0000 | 0.575 | 0.0000 | 0.775 | 0.0000 |
| 0.180 | 0.0166 | 0.380 | 0.0000 | 0.580 | 0.0000 | 0.780 | 0.0000 |
| 0.185 | 0.3166 | 0.385 | 0.0018 | 0.585 | 0.0000 | 0.785 | 0.0000 |
| 0.190 | 0.0000 | 0.390 | 0.0001 | 0.590 | 0.0000 | 0.790 | 0.0000 |
| 0.195 | 0.0000 | 0.395 | 0.0000 | 0.595 | 0.0000 | 0.795 | 0.0000 |
| | | | | | | 0.800 | 0.0000 |

$t$ is time on record in seconds.
$P$ is probability that a reflection occurs at time $t$.

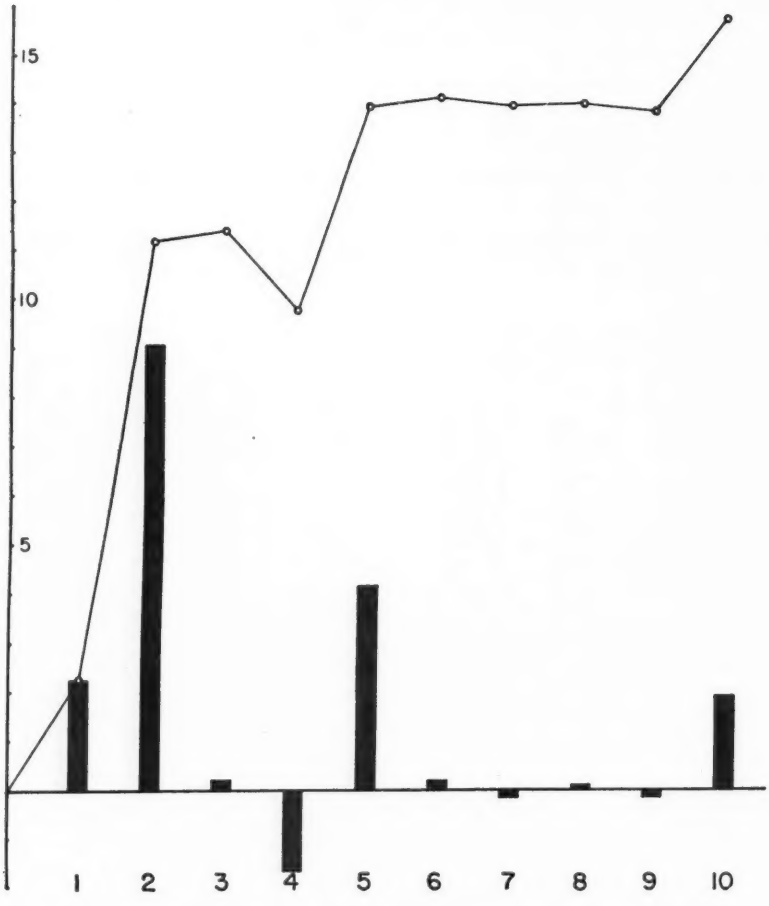


FIG. 4. Individual and cumulative amounts of information obtained by analysis of successive traces, given by changes in entropy.

the last trace of Figure 3. In actual applications a great deal of time could be saved in this way. However, the example submitted here was computed to demonstrate the successive changes in the probability distributions caused by the individual traces. It may often happen that more information regarding the structure of a seismogram can be gained by the study of this variation than by a study of the cumulative last trace. This could be particularly true in case there is more than one reflection in the interval under study.

As a test of the amount of information supplied by the proposed method, the data in Figure 4 were computed and plotted.

Shannon's formula (Shannon and Weaver, 1949)

$$H = -\sum_{r=1}^{n} P_{ri} \log_2 P_{ri}$$

allows us to compute the entropy $H$ as the probability distribution for each trace becomes available. A drop in entropy means a gain of information so that the amount of information supplied by each trace can be measured by the change in entropy. This change is plotted in Figure 4 for each trace in heavy black lines. The cumulative information is shown by the thin line plotted against each trace indicated on the horizontal scale.

Most of the information gained was obtained from traces 1, 2, 5, and 10. Trace 4, on the other hand, was so noisy that information was actually lost in the process of analysis. This suggests that convergence can be increased by the proper selection of the traces to be analyzed and the order in which they are considered. This fact also contributes an important time-saving factor: for any point where the prior probability is zero, integral (6) does not have to be computed. By choosing the traces in order of decreasing quality a large number of zero probabilities can be obtained quickly.

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GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955), PP. 254–269, 5 FIGS.

# SIMILARITY OF OUTPUT TRACES AS A SEISMIC OPERATOR CRITERION*

STEPHEN M. SIMPSON, JR.†

## ABSTRACT

The problem of emphasizing signals on multiple trace seismograms is approached by considering a relationship between the input and output records. It is proposed that the transformation to output record be one which causes the output traces to be most "similar" or "in phase" according to a certain definition of this property. If the noise and signal are "properly behaved," it may be demonstrated that a linear transformation chosen by this criterion must have a response emphasizing frequency ranges of high input signal-to-noise ratio. The determination of such a transformation from the input data alone is carried out for discrete linear operators. The numerical work involved in computing such operators is formidable. As an example the computations were carried out for a mixture of an artificial signal introduced into a noise record. The results are about as good as those obtained with conventional filtering techniques depending on prior knowledge of input signal-to-noise ratios.

## INTRODUCTION

In a recent article in GEOPHYSICS (Wadsworth et al., 1953) the use of linear operators was introduced as a means for detecting seismic reflections. The article reviewed the concepts of modern statistical methods of time series analysis as they relate to the special problems encountered in seismogram interpretation, and illustrated analysis techniques based on those concepts. Since that time, work along these lines has continuted at MIT in the Geophysical Analysis Group, a research project in the department of Geology and Geophysics, directed initially by E. A. Robinson. The project is supported by interested oil and geophysical companies and operates under an MIT advisory committee composed of G. P. Wadsworth, P. M. Hurley, and J. G. Bryan. Its findings have been presented in four reports (MIT Geophysical Analysis Group, 1953*a*, 1953*b*, 1953*c*, 1954)[1] and discussed at two conferences. It has been with this group that the author carried out the work described in the present paper.

The above-mentioned issue of GEOPHYSICS also carried a very interesting article by Frank and Doty (1953) which described an experiment in reflection picking by classical electrical engineering techniques. Similar experiments, treating the same data by statistical methods, were conducted by the MIT group (MIT G.A.G., 1954; Smith, 1954) because of the instructive comparisons they provided between the approaches taken and because Frank and Doty's data afforded good experimental control. For the same reasons their data are used to illustrate the procedures to be discussed in this paper.

A linear operator may be chosen in a variety of ways to treat data, each pro-

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[1] Reproductions of these reports are obtainable through the MIT Central Library. Special Collections Division.

cedure depending on a different formulation of, or approach to, the problem to be solved. In addition to the methods discussed by Wadsworth et al. (1953), other criteria for choosing linear operators have been described (Wiener, 1950; Van Vleck and Middleton, 1946, MIT G.A.G., 1954; Smith, 1954). The relative applicability of these methods will vary with the data treated inasmuch as one set of data will more nearly satisfy the problem formulation of a certain method than will another set. It is, of course, for this reason that the development of different methods is important. The procedure to be developed here arises from one set of assumptions about the problem, and naturally will not apply in all cases. It is, however, supplied with facilities for checking, at an early stage, how well the data satisfy the formulation used and for making certain adjustments depending on these checks.

## FORMULATION OF THE METHOD OF SIMILAR OUTPUT

We begin with a fairly rigid statement of the problem. A certain portion of a multi-trace, unmixed seismogram is to be studied. We proceed to make the following assumptions about the structure of this information. First of all, each trace is to consist of a linear superposition of a signal or reflection pulse and an interference or noise component. Secondly, the signal as represented on a trace is to be identical in shape and location with that of any other trace. Lastly, the noise contributions are assumed to be random samples from members of an ensemble of stationary time series. Thus the noise on all traces will have approximately the same power-frequency characteristics, but phase relations between noise on different traces will be random. The effects of various types of departures from these assumptions will be discussed later.

We now wish to treat these data for better interpretation. Each trace of the record is to be acted upon by the same linear operator so as to generate an output or filtered trace. The resulting filtered record is required to emphasize the signal contribution and the linear operator is to be chosen so as to effect this emphasis according to some optimum criterion. Since very little is known about the given signal and noise mixture, attention is turned to the output record.

The output or filtered record should have the reflection signal plainly visible and, ideally, no noise present. It this were possible all output traces would be identical. Practically, this is impossible and our actual optimum filter should produce a record in which reflections make a maximum possible contribution. Again the traces will be quite similar, at least during the reflection. It is this desirable similarity of output traces which will be established as the criterion for optimization of the filter. We shall require our optimum filter to be one which produces greatest similarity in these traces. Whether or not this procedure will in reality emphasize the signal will be considered after a closer consideration of "similarity."

We must now define a measure of similarity by which we can determine the effectiveness of our filter. Suppose the output traces are numbered $T^1$, $T^2$, $\cdots$,

$T^L$. Form the artificial traces $T^1-T^2$, $T^2-T^3$, $\cdots$, $T^i-T^{i+1}$, $\cdots$, and $T^1+T^2$, $T^2+T^3$, $\cdots$, $T^i+T^{i+1}$, $\cdots$. Determine the power $(\int f(t)^2 dt)$ in $T^i-T^{i+1}$ and $T^i+T^{i+1}$. Then take as a measure of similarity the ratio

$$\lambda = \frac{\sum_{j=1}^{L-1} \text{Power } (T^j - T^{j+1})}{\sum_{j=1}^{L-1} \text{Power } (T^j + T^{j+1})} . \tag{1}$$

It is apparent that if the traces are all identical, $\lambda$ will be zero, whereas if they are alternatively out of phase or dissimilar, $\lambda$ becomes infinite. Hence we shall require $\lambda$ to be a minimum.

It may now be argued that, in choosing our linear operator by this criterion, we are actually forcing the response function of the operator to be peaked at the point of maximum signal-to-noise ratio. We use the notation in the following table to describe the structure of the problem.

| | TRACE | | NOISE COMPONENT | | SIGNAL COMPONENT |
|---|---|---|---|---|---|
| INPUT | $t_i^j$ | = | $n_i^j$ | + | $s_i^j$ |
| | LIN. OPER. ↓ | | LIN. OPER ↓ | | LIN. OPER. ↓ |
| OUTPUT | $T_i^j$ | = | $N_i^j$ | + | $S_i^j$ |

In this notation the time functions, such as $T^j(t)$ are assumed to have been converted to time series of zero mean, such as $T_i^j$, by reading values of the functions at equally spaced intervals ($h$ seconds apart), so that

$$T^j(t) = T_i^j \qquad \text{when } t = ih.$$

We are interested in the time interval $t=0$ to $t=A$ so that the index $i=0, 1, 2, \cdots, k$ where $k=A/b$. Analogous relations hold for the other time functions. With respect to the $N_i^j$ series, it should be mentioned that they, having been derived by a single linear operation on the ensemble $n_i^j$, also constitute an ensemble of stationary time series.

In this notation, then, $\lambda$ may be reduced as follows:

$$\lambda = \frac{\sum_{j=1}^{L-1} \text{Power } (T_i^j - T_i^{j+1})}{\sum_{j=1}^{L-1} \text{Power } (T_i^j + T_i^{j+1})} = \frac{\sum_j \text{Power } (N_i^j - N_i^{j+1})}{\sum_j \text{Power } (N_i^j + N_i^{j+1} + 2S_i)}$$

$$= \frac{\sum_j \sum_{i=0}^{k} (N_i^j - N_i^{j+1})^2}{\sum_j \sum_{i=0}^{k} (N_i^j + N_i^{j+1} + 2S_i)^2}$$

$$\lambda = \frac{\sum_j \left[ \sum_i (N_i^j)^2 + \sum_i (N_i^{j+1})^2 - 2 \sum_i (N_i^j N_i^{j+1}) \right]}{\sum_j \left[ \sum_i (N_i^j)^2 + \sum_i (N_i^{j+1})^2 + 4 \sum_i (S_i)^2 + 2 \sum_i N_i^j N_i^{j+1} + 2 \sum_i S_i (N_i^j + N_i^{j+1}) \right]}. \quad (2)$$

For a sufficient number of traces ($L$ large) this expression is dominated by the squared terms. These terms represent the power in the various series squared. The other terms represent zeroth lag cross-correlations between either noise on a trace and that on an adjacent trace or between noise and signal. These quantities will assume positive and negative values distributed around zero, due to the random phase aspects of the noise, and will tend to be negligible in the summation over $j$. Using the fact that the power in $N_i^j$ is nearly independent of $j$, $\lambda$ then reduces to the following:

$$\lambda = \frac{2(L-1)(\text{Average Noise Output Power})}{2(L-1)(\text{Average Noise Output Power}) + 4(L-1)(\text{Signal Output Power})}$$

or

$$\lambda = \frac{\text{Average Noise Output Power}}{\text{Average Noise Output Power} + 2(\text{Signal Output Power})}. \quad (3)$$

It is readily verified that this expression is minimized when

$$\frac{\text{Signal Output Power}}{\text{Average Noise Output Power}} \quad (4)$$

is maximized.

No operator could maximize expression (4) better than one whose response function consisted of a spike at the point of maximum input signal-to-noise ratio. It is therefore natural to expect that practical linear operators, whose response functions are subject to limitations, must emphasize regions of high signal-to-noise ratio to the best of their ability when they are chosen so as to minimize $\lambda$. These results are analogous to those found by Smith (1954) in treating directional filtering aspects of multiple seismometer groups.

Expression (3) gives us a measure of the output signal-to-noise power ratio, but it may also be used for determining input signal-to-noise ratio if $\lambda$ is applied to the unfiltered record. The ratio is

$$\frac{\text{Signal Power}}{\text{Noise Power}} = 1/2(1/\lambda - 1). \quad (5)$$

This is not the ratio of peaks on the amplitude spectra, but the ratio of the integrated power spectra, relative to the interval length chosen. We shall use this definition of signal-to-noise ratio, although the *point* of maximum signal-to-noise ratio is the same whether chosen from amplitude or power spectra.

## THE DETERMINATION OF THE OPERATOR

So far we have shown what characteristics an operator should have in order to minimize the ratio $\lambda$. We have not as yet developed a method for determining such an operator. This development is carried through here using matrix notation.

If $a_0, a_1 \cdots a_s \cdots a_m$ represent the operator coefficients to be optimized, then the $j$th input and output traces are related as follows:

$$\begin{bmatrix} t_0^j & t_{-1}^j & t_{-2}^j \cdots & t_{-m}^j \\ t_1^j & t_0^j & t_{-1}^j \cdots & \\ t_2^j & & & \vdots \\ \vdots & & & \vdots \\ \vdots & & & \vdots \\ t_k^j \cdots & & & t_{k-m}^j \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ \vdots \\ \vdots \\ a_m \end{bmatrix} = \begin{bmatrix} T_0^j \\ T_1^j \\ T_2^j \\ \vdots \\ \vdots \\ T_k^j \end{bmatrix} \tag{6}$$

or

$$\boldsymbol{t}^j \boldsymbol{a} = \boldsymbol{T}^j.$$

Forming the artificial sum and difference traces we get

$$\boldsymbol{T}^j - \boldsymbol{T}^{j+1} = (\boldsymbol{t}^j - \boldsymbol{t}^{j+1})\boldsymbol{a}$$
$$\boldsymbol{T}^j + \boldsymbol{T}^{j+1} = (\boldsymbol{t}^j + \boldsymbol{t}^{j+1})\boldsymbol{a},$$

and their respective power contents become

$$\text{Power } (\boldsymbol{T}^j - \boldsymbol{T}^{j+1}) = \boldsymbol{a}^T(\boldsymbol{t}^j - \boldsymbol{t}^{j+1})^T(\boldsymbol{t}^j - \boldsymbol{t}^{j+1})\boldsymbol{a}$$
$$\text{Power } (\boldsymbol{T}^j + \boldsymbol{T}^{j+1}) = \boldsymbol{a}^T(\boldsymbol{t}^j + \boldsymbol{t}^{j+1})^T(\boldsymbol{t}^j + \boldsymbol{t}^{j+1})\boldsymbol{a},$$

where the superscript $^T$ designates the transpose. Summing these powers over all traces, $\lambda$ may then be written

$$\lambda = \frac{\boldsymbol{a}^T\left[\sum_{j=1}^{L-1} (\boldsymbol{t}^j - \boldsymbol{t}^{j+1})^T(\boldsymbol{t}^j - \boldsymbol{t}^{j+1})\right]\boldsymbol{a}}{\boldsymbol{a}^T\left[\sum_{j=1}^{L-1} (\boldsymbol{t}^j + \boldsymbol{t}^{j+1})^T(\boldsymbol{t}^j + \boldsymbol{t}^{j+1})\right]\boldsymbol{a}}, \tag{7}$$

or more briefly

$$\lambda = \frac{\boldsymbol{a}^T\boldsymbol{A}\boldsymbol{a}}{\boldsymbol{a}^T\boldsymbol{B}\boldsymbol{a}}, \tag{8}$$

where the square matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ may be computed directly from the input

data. The determination of $\boldsymbol{a}$ is now mathematically equivalent to the ratio-of-squares criterion of Smith (1954).

To minimize $\lambda$, the variation in $\lambda$ must be zero.

$$\partial\lambda = 0 = \frac{(\boldsymbol{a}^T\boldsymbol{B}\boldsymbol{a})\partial(\boldsymbol{a}^T\boldsymbol{A}\boldsymbol{a}) - (\boldsymbol{a}^T\boldsymbol{A}\boldsymbol{a})\partial(\boldsymbol{a}^T\boldsymbol{B}\boldsymbol{a})}{(\boldsymbol{a}^T\boldsymbol{B}\boldsymbol{a})^2}$$

$$= \frac{1}{\boldsymbol{a}^T\boldsymbol{B}\boldsymbol{a}}\left[\partial(\boldsymbol{a}^T\boldsymbol{A}\boldsymbol{a}) - \lambda\partial(\boldsymbol{a}^T\boldsymbol{B}\boldsymbol{a})\right].$$

Thus

$$\partial(\boldsymbol{a}^T\boldsymbol{A}\boldsymbol{a}) - \lambda\partial(\boldsymbol{a}^T\boldsymbol{B}\boldsymbol{a}) = 0$$
$$\partial\boldsymbol{a}^T[\boldsymbol{A} - \lambda\boldsymbol{B}]\boldsymbol{a} = 0.$$

But since the $a_j$'s are independent,

$$[\boldsymbol{A} - \lambda\boldsymbol{B}]\boldsymbol{a} = 0. \tag{9}$$

Hence the determinant of the bracketed matrix must vanish to obtain a non-trivial solution. If we write this in the form

$$|\boldsymbol{A} - \lambda\boldsymbol{B}| = 0,$$

then

$$|\boldsymbol{A} - \lambda\boldsymbol{B}| = |\boldsymbol{B}^{-1}\boldsymbol{A}\boldsymbol{B} - \lambda\boldsymbol{B}^{-1}\boldsymbol{B}\boldsymbol{B}|$$
$$= |(\boldsymbol{B}^{-1}\boldsymbol{A} - \lambda\boldsymbol{I})\boldsymbol{B}|$$
$$= |(\boldsymbol{B}^{-1}\boldsymbol{A} - \lambda\boldsymbol{I})| \cdot |\boldsymbol{B}| = 0$$

where $\boldsymbol{I}$ is the unit matrix.

But $\boldsymbol{B}$ is non-singular since it has the form $\Sigma\boldsymbol{X}^T\boldsymbol{X}$, and its determinant is non-zero. Thus

$$|\boldsymbol{B}^{-1}\boldsymbol{A} - \lambda\boldsymbol{I}| = 0. \tag{10}$$

Equation (10) tells us that the solution is obtained by finding the lowest eigenroot of the matrix $\boldsymbol{B}^{-1}\boldsymbol{A}$ and using this as the value of $\lambda$ in solving the homogeneous system of equations (9) for $\boldsymbol{a}$.

As it is more convenient to compute largest eigenroots, $\lambda_{min}$ may be computed as the reciprocal of the maximum eigenroot of $\boldsymbol{A}^{-1}\boldsymbol{B}$. Furthermore, if an iterative procedure is used to find this root, the associated eigenvector is found simultaneously and represents the desired solution for $\boldsymbol{a}$. See Frazer et al. (1952) and Hildebrand (1952, Chapter 1) for further details on this and other aspects of matrix manipulation.

## DEPARTURES FROM ASSUMED CONDITIONS

Probably the least damaging departures which an actual record may take from the assumed conditions are those which concern the signal. If we assume the

requirements on the noise contributions are satisfied, then we may distinguish at least three common ways in which the appearance of the actual signal may differ from that assumed, *viz.* no signal is present, signal strength varies from trace to trace, and stepout exists between traces.

If no signal exists in the interval studied, this will be evident from applying equation (5) to determine input signal-to-noise ratio. If this ratio is very small, nothing further need be done.

A reasonable variation in signal strength (not shape) should not be very damaging. In this case, a few more terms must be added to equation (2), and equation (3) is not exactly true. However, a 10 per cent variation of signal amplitude from trace to trace modifies the numerator of (3) by only $\frac{1}{2}$ of 1 percent of the output signal-to-noise ratio, while the denominator is unaffected. This is probably too small an effect to modify materially the conclusions of that section.

Stepout of signal is again not too serious when it is reasonably small between adjacent traces. The reason is that this procedure employs mixing in both the time domain and in the correlation functions (see below), and the time domain mixing is limited to pairs of adjacent traces. Phase information has been discarded in the mixing of correlations so stepout cannot affect this part of the method. If, however, there is reason to suspect large stepout, one method of correcting for it is to introduce trial stepouts artificially in the input and evaluate equation (5) for each trial. This quantity should be a maximum for the correct stepout, and the optimum operator should be the one determined with the correct trial stepout in the input.

When the noise contribution does not satisfy the assumptions made about it, the problem is more serious. The cross-correlations of equation (2) need not be negligible, and we may imagine that the procedure will treat frequency components from noise, which are on the average, in phase between traces as though they were parts of the signal. The input signal-to-noise ratio from equation (5) will indicate more signal present than actually exists. However, there is information to the matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ (equations (7) and (8)), computed directly from the input data, which may help us decide if we are dealing with this kind of a situation.

Consider the $\boldsymbol{A}$ matrix

$$\boldsymbol{A} = \sum_{i=1}^{L-1} (\boldsymbol{t}^i - \boldsymbol{t}^{i+1})^T (\boldsymbol{t}^i - \boldsymbol{t}^{i+1}).$$

It consists of the sum of $L-1$ auto-correlation matrices (Wadsworth et al., 1953) for the artificial traces $\boldsymbol{t}^i - \boldsymbol{t}^{i+1}$. Using the relation that $\boldsymbol{t}^i = \boldsymbol{t}^i + \boldsymbol{s}$ and *not dropping any terms* we find that

$$(\boldsymbol{t}^i - \boldsymbol{t}^{i+1})^T (\boldsymbol{t}^i - \boldsymbol{t}^{i+1}) = (\boldsymbol{n}^i)^T (\boldsymbol{n}^i) + (\boldsymbol{n}^{i+1})^T (\boldsymbol{n}^{i+1}) - [(\boldsymbol{n}^i)^T (\boldsymbol{n}^{i+1}) + (\boldsymbol{n}^{i+1})^T (\boldsymbol{n}^i)].$$

Thus the auto-correlation function comprising say the first row of this matrix may be written

$$\phi_{t^j - t^{j+1}, t^j - t^{j+1}}(\tau) = \phi_{n^j, n^j}(\tau) + \phi_{n^{j+1}, n^{j+1}}(\tau) - [\phi_{n^j, n^{j+1}}(\tau) + \phi_{n^j, n^{j+1}}(-\tau)], \quad (11)$$

where $\phi_{x,y}(\tau)$ denotes the correlation function between $x$ and $y$.

Setting the bracketed quantity of equation (11) equal to $\psi_{n^j, n^{j+1}}(\tau)$ and summing over $j$, the auto-correlation function comprising a row of the matrix $A$ becomes

$$\phi_{A,A}(\tau) = 2(L-1)\overline{\phi_{n,n}(\tau)} - \sum_{j=1}^{L-1} \psi_{n^j, n^{j+j}}(\tau)$$

where the bar indicates an average.

Similarly

$$\phi_{B,B}(\tau) = 2(L-1)\overline{\phi_{n,n}(\tau)} + 4(L-1)\phi_{s,s}(\tau) + \sum_{j=1}^{L-1} \psi_{n^j, n^{j+1}}(\tau) + 2\sum_{j=1}^{L-1} [\psi_{n^j, s}(\tau) + \psi_{n^{j+1}, s}(\tau)].$$

Now, it the noise *does* satisfy the assumptions, the $\phi_{A,A}$ and $\phi_{B,B}$ are dominated by the auto-correlation functions $\phi_{n,n}$ and $\phi_{s,s}$, and so

$$\left.\begin{aligned} \phi_{A,A}(\tau) &\approx 2(L-1)\overline{\phi_{n,n}(\tau)} \\ \phi_{B,B}(\tau) &\approx 2(L-1)\overline{\phi_{n,n}(\tau)} + 4(L-1)\phi_{s,s}(\tau) \\ \phi_{B,B}(\tau) - \phi_{A,A}(\tau) &\approx 4(L-1)\phi_{s,s}(\tau) \end{aligned}\right\}. \quad (12)$$

Thus we find that, if the data are properly behaved, a row of the matrix $A$ should resemble an autocorrelation function corresponding to the average noise input, while a row of the difference matrix $B-A$ should resemble the autocorrelation function of the input signal.

The above situation is disturbed when the noise assumptions are not upheld. In this case the functions $\psi$ contribute to $\phi_{AA}$ and $\phi_{BB}$ and their presence may be detected in possibly two ways. First of all, the $\psi$ functions, while they are symmetric do not necessarily possess a fundamental property of autocorrelations of this type, namely that the cosine transforms are nearly everywhere positive. The second method is possible when the shape of the suspected signal is approximately known. If so, limits may be put on the possible signal autocorrelation functions and compared with $\phi_{BB}-\phi_{AA}$. If both tests fail, the assumptions are almost certainly not upheld and the present criterion for choosing the linear operator will not give optimum results.

## EXAMPLE

As mentioned previously, in order to illustrate the application of this method under controlled conditions which approximate an actual seismic case, data taken from Frank and Doty (1953) are handled by the technique just proposed. Frank

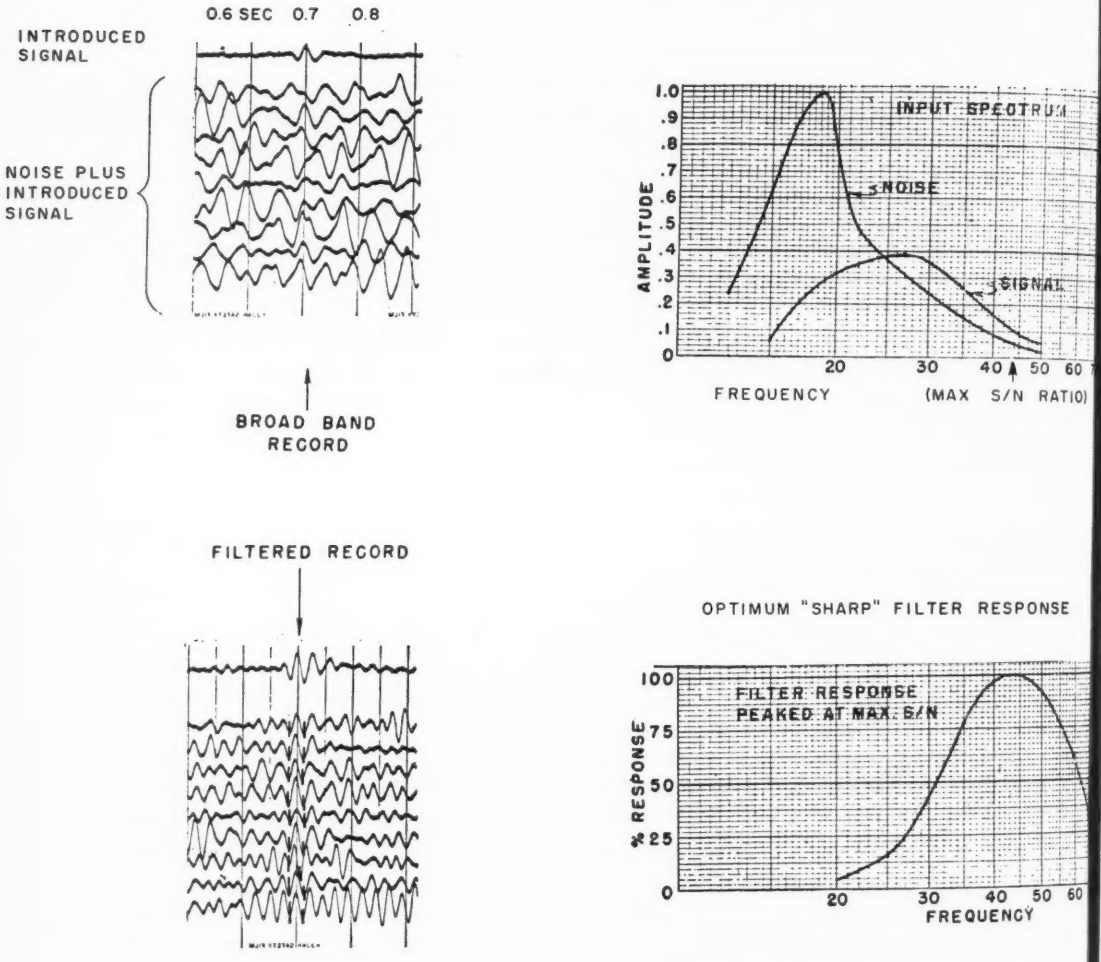


FIG. 1. Experiment conducted by Frank and Doty. Diagrams from Frank and Doty (1953, p. 591).

and Doty introduced an artificial pulse into all traces of a record considered to be pure "noise," and proceeded to demonstrate (in one aspect of their study) that the optimum filter from the standpoint of signal-to-noise ratio improvement was one peaked at maximum input-signal-to-noise ratio. Figure 1, consisting of diagrams from their article, shows the input signal and noise spectra, the optimum filter response, and the broad band and filtered records.

Using these data, we intend to show first that they are properly behaved for application of the present method. Then it may be demonstrated that linear operators determined in this fashion do have response functions emphasizing regions of high signal-to-noise input ratio.

As a practical matter, it is important to know the restrictive behavior of

finite operator length (finite $m$ in equation (6)). For a large number of terms in the operator, $m+1$, the response function is less restricted in being able to peak at the point of maximum signal-to-noise ratio than it is for a small number of terms. Hence the procedure has been carried through for several values of $m$ to show the effect of this parameter.

*The Matrices **A** and **B***

The interval selected for study bracketed the introduced pulse and was three times the pulse length. Digitization of the data was accomplished by reading values off the traces at 2.5 millisecond intervals, and the matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ were computed on Whirlwind I at M.I.T., for a 16-term operator. For smaller operators, sub-matrices were taken.

The input signal-to-noise ratio as determined by equation (5) was .17/1. This indicated a certain signal content, whose autocorrelation as was determined from $\boldsymbol{A}$ and $\boldsymbol{B}$ by equation (12) is shown by the solid curve of Figure 2a. The fact that this computed function represents a pulse autocorrelation reasonably well is verified by the dashed line of Figure 2a. It shows the autocorrelation of the true pulse, which we happen to know exactly in this test situation.

Figure 2b shows the cosine transforms of $\phi_{BB}$ and of $\phi_{BB}-\phi_{AA}$. These may be thought of as estimates of the power frequency ranges which the method is trying to discriminate. The curves are in general positive, which is added evidence that the data nearly satisfy the assumptions we wish them to satisfy. We know the true signal and noise spectra (amplitude spectra of Figure 1) and the comparison of the estimated spectra with them is not unfavorable.

*$\lambda_{min}$ and the Optimum Operators*

Figure 3 shows various curves and their dependence on the parameter $m$. $\lambda_{\min}$ was obtained as the inverse of the largest eigenroot of $\boldsymbol{A}^{-1}\boldsymbol{B}$ rather than as the minimum eigenroot of $\boldsymbol{B}^{-1}\boldsymbol{A}$. The characteristic polynomials of $\boldsymbol{A}^{-1}\boldsymbol{B}$ for 1-, 2-, 3-, and 4-term operators were determined and are plotted in Figure 3a. These curves hug the axis very closely in the region of the roots (all of which are real) and demonstrate the need for maintaining accuracy in computation.

$\lambda_{\min}$ was also obtained from 8- and 16-term operators. A graph of $\lambda_{\min}$ versus $m+1$ is shown in Figure 3b, and may be interpreted as a graph of the measure of effectiveness of an $(m+1)$-term operator in satisfying the criterion being considered. The curve is asymptotic to the dotted line which would be $\lambda_{\min}$ for an unrestricted operator according to the maximum input signal-to-noise ratio of Figure 1. $\lambda_{\min}$ for the 16-term operator corresponds to an output signal-to-noise ratio of 1.3/1.

Having determined the operator coefficients $a_s$, one can obtain the corresponding power responses from the relation (MIT G.A.G., 1954; Smith, 1954)

$$H^2(\omega) = \phi(0) + 2\sum_{\tau=1}^{m} \phi(\tau) \cos \omega h\tau$$

where

$$\phi(\tau) = \sum_{s=0}^{m-\tau} a_s a_{s+\tau}.$$

The power responses for the various operators (Figure 3c) help describe what is happening. Apparently all that the small term operators can do in this case is to amplify high frequencies. This is to be expected. Only low-order harmonics can

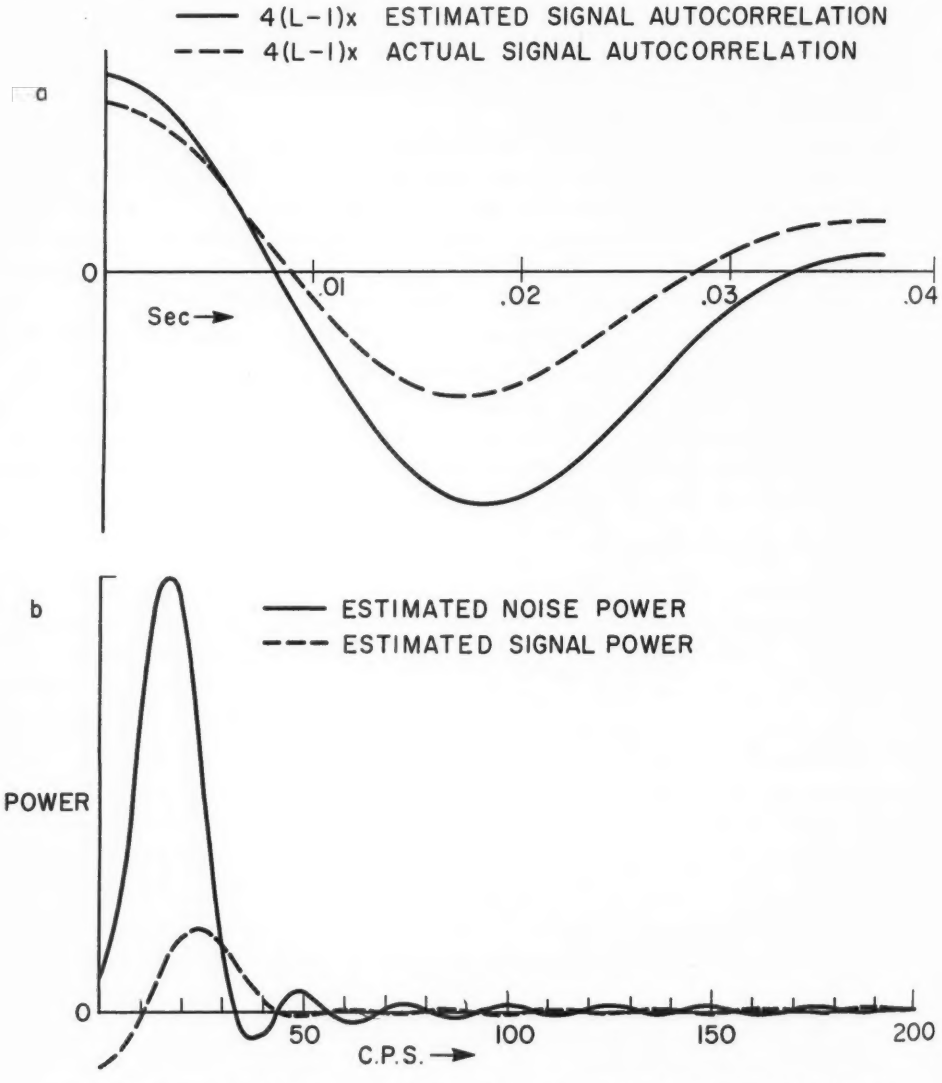


FIG. 2. a) Comparison of $\phi_{BB}-\phi_{AA}$ with $4(L-1)$ times actual signal autocorrelation. b) Approximated frequency distributions which are to be separated.

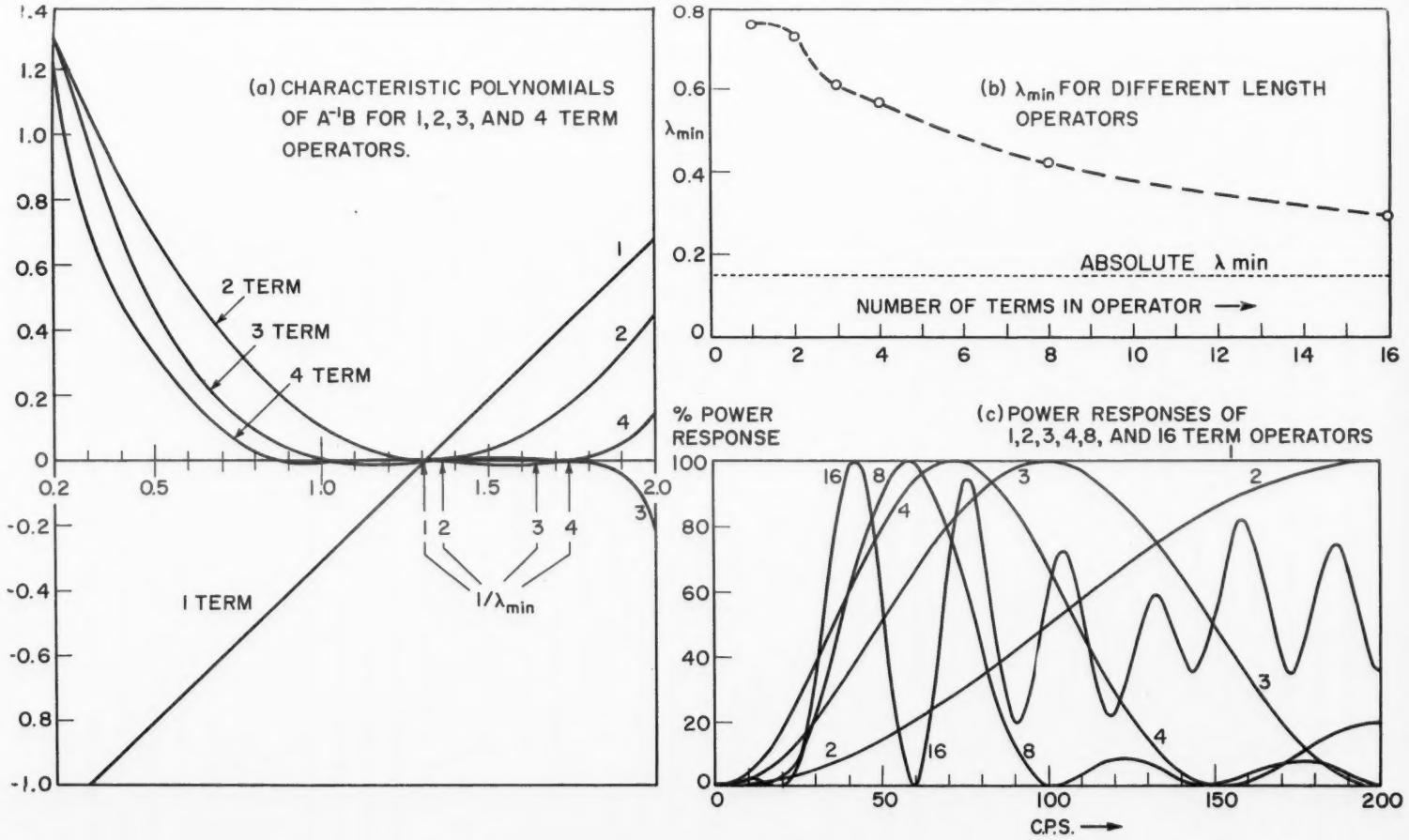
(a) CHARACTERISTIC POLYNOMIALS OF A⁻¹B FOR 1, 2, 3, AND 4 TERM OPERATORS.
2 TERM
3 TERM
4 TERM
1 TERM
1/λmin
(b) λmin FOR DIFFERENT LENGTH OPERATORS
λmin
ABSOLUTE λ min
NUMBER OF TERMS IN OPERATOR
% POWER RESPONSE
(c) POWER RESPONSES OF 1, 2, 3, 4, 8, AND 16 TERM OPERATORS
C.P.S.

FIG. 3. Comparisons between operators of different lengths.

appear in their response curves and the maximum signal-to-noise ratio (Figure 1) does occur on the high-frequency side of peak power. As the number of terms increases, the maximum of the response curve moves to lower frequencies and settles down in the region of maximum signal-to-noise ratio (about 45 cps.). The high frequency behavior of the 16-term operator may be spurious due to computational errors, but the response may well adjust itself radically in regions of low power in order to sharpen up the peak around 45 cps.

Figure 4 shows separately the amplitude and phase responses (MIT G.A.G., 1954; Smith, 1954)

$$H(\omega) = \sum_{s=0}^{m} a_s e^{-i\omega h s}$$

for the 4-, 8-, and 16-term operators. These three operators were used to filter the broad band record of Figure 1. The filtered records appear in Figure 5. While the signal may be discerned on the record derived from the 4-term operator, it is brought out much more strongly by the 8-term operator. On the other hand, the addition of 8 more terms to the operator has not brought about a proportionate increase in record improvement (Figure 5c).

## SUMMARY AND CONCLUSIONS

In this paper we have set up a mathematical model of a signal-noise problem which, in some instances, should be similar to those encountered on multiple trace seismograms. In terms of this model, the procedure presented for solution automatically adjusts itself so as to have characteristics which are otherwise known to be desirable. Whereas other techniques utilizing these characteristics may require detailed knowledge of the problem for application, the procedure presented here replaces this requirement with a set of assumptions which, if upheld, lead directly to this knowledge. The method will fail according to the manner and degree in which the assumptions are not upheld. In a test situation reasonably upholding the assumptions, the expected behavior was observed.

The computations involved deserve comment as they are by no means trivial. Required successively are: record digitization; formation of sum and difference traces; computation of correlation matrices; addition of matrices; matrix inversions; matrix multiplication; eigenroot and eigenvector determination; output record computation; and graphing of results. In addition, various power spectra and response functions may be desired. For a large number of traces and many-termed operators, the work is very considerable and severely limits experimentation. In view of this, the author wishes to point out the important role played by the high-speed digital computer, without which many discussions of this type would remain largely of academic interest only. The majority of the computations connected with the work presented here was done on the Whirlwind I Digital Computer, machine time on which was made possible by the Office of Naval Research.

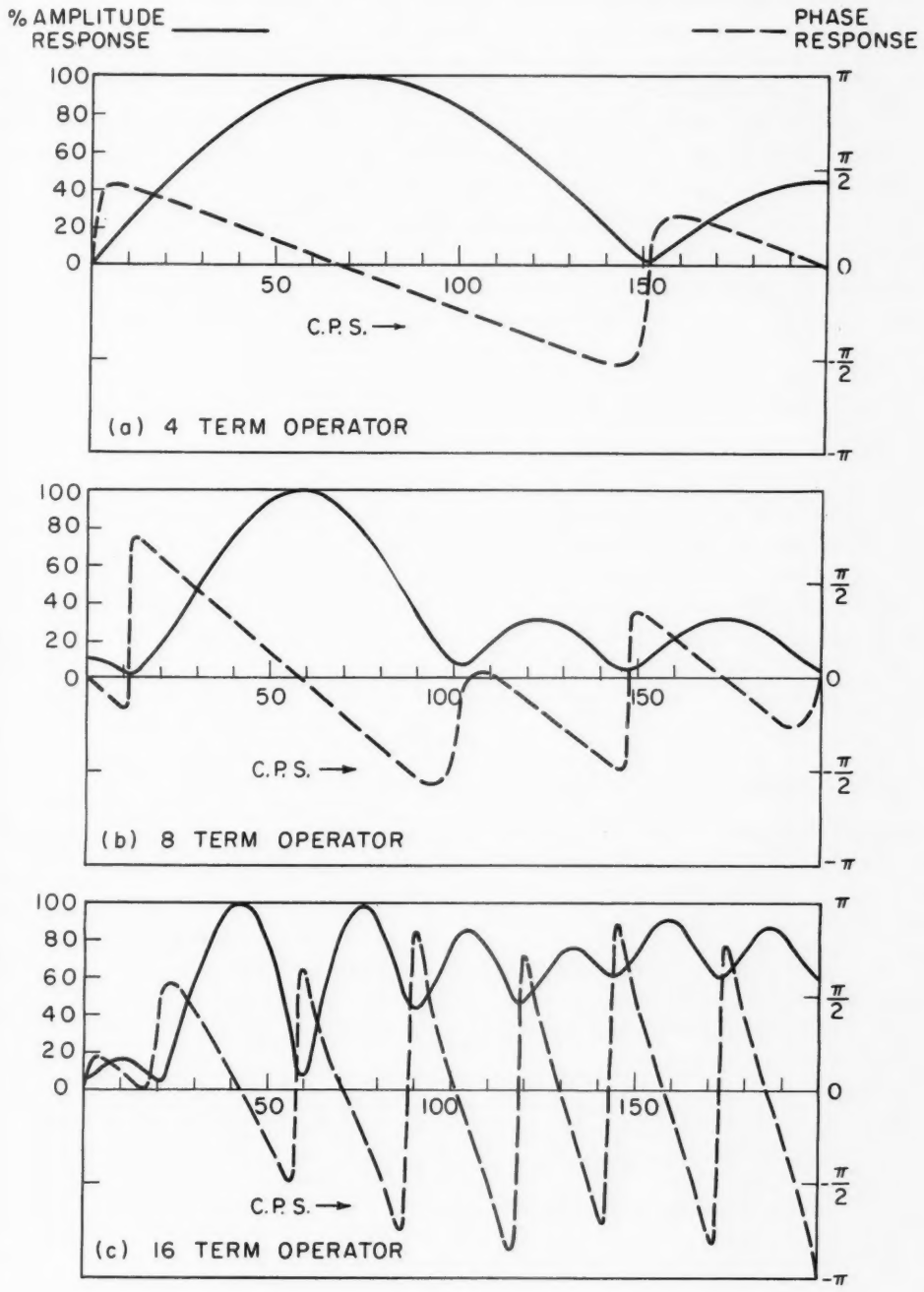


FIG. 4. Frequency responses of 4-, 8-, and 16-term operators.

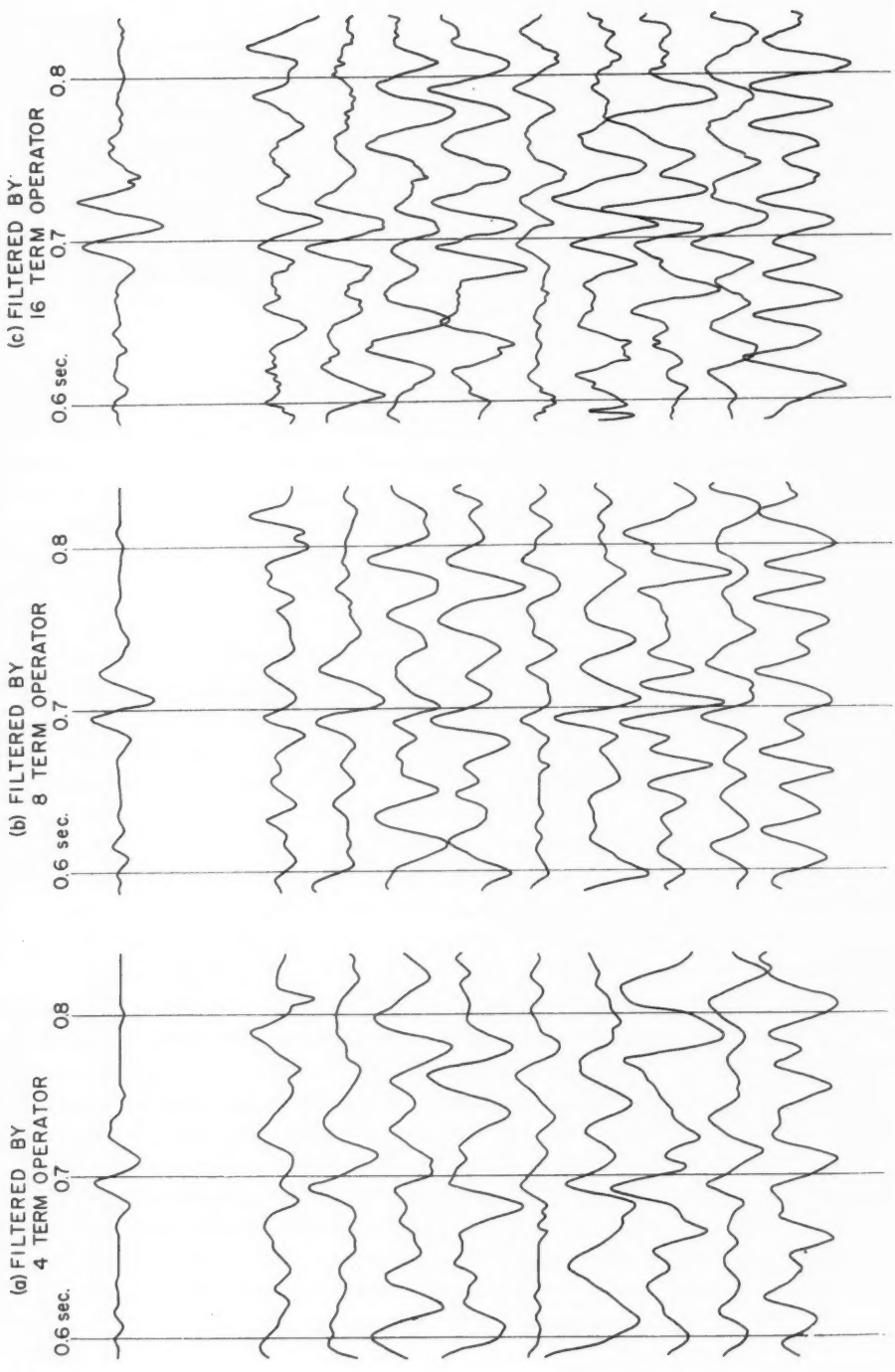


FIG. 5. Broad band record of Figure 1 filtered by "similar output" operators.

However, it is possible to obtain useful results without following through the entire treatment. For instance, the application of equation (5) to adjacent or overlapping intervals down the entire record should serve to define regions of possible reflections. Then the use of correlation analysis as indicated will yield estimates of frequency ranges to be separated. These estimates may be useful in themselves, and furthermore can be obtained with suitable analogue equipment directly from, say, magnetic recordings, thus obviating the need for digitization.

In conclusion, the author should like to repeat that the procedure here presented represents a solution to but one formulation of the signal-noise problem. It hardly needs mentioning that its practical value must be determined after balancing many factors in competition with other procedures.

ACKNOWLEDGMENTS

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GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955), PP. 270-282, 8 FIGS.

# A DEEP-SEA SEISMIC REFLECTION PROFILE*

C. B. OFFICER†

## ABSTRACT

This paper presents a detailed seismic reflection profile taken over the deep ocean. Clear sub-bottom reflections and refractions are obtained which are interpretable to show the variation of velocity with depth. From the travel-time difference between the bottom reflection and a prominent sub-bottom reflection as a function of range and frequency and from the variation of the amplitudes of the bottom and sub-bottom reflections with frequency and angle of incidence, the conclusion is reached that the sediment is dispersive, i.e, that the velocity of sound propagation through it is a function of frequency. Further it is concluded that at lower frequencies the velocity in the sediment near the bottom is less than that in the adjacent ocean. This rather unexpected geophysical phenomenon is explained theoretically in terms of propagation in a porous media.

The low velocity sediment forms a wave guide between the higher velocity ocean above and the higher velocity sediment beneath. This resulant wave guide explains previously observed single-frequency arrivals.

## INTRODUCTION

A great deal of work has been done in recent years in the study of suboceanic geologic structure by the seismic refraction method. Reports, published and in preparation, from Lamont Geological Observatory, Columbia University; Scripps Institution of Oceanography; Dept. of Geodesy and Geophysics, Cambridge University; and Woods Hole Oceanographic Institution describe much of this work. The amount of effort put into seismic reflection measurements has not been so vast. This has been because information was at first primarily desired on the gross features of the oceanic areas. Among such features are the depth of the Mohorovičić discontinuity, the properties of the crustal material, and the total volume of sediment under the abyssal plains. Geophysicists were also concerned with the changes that occur across continental margins, oceanic islands and ridges, island arcs, and interior basins.

At present the emphasis is changing toward a closer examination of the sediment column itself. The seismic reflection method is finding important use in these studies. Weibull (1947) and Hersey and Ewing (1949) describe vertical reflection measurements, and the latter discuss various types of reflection records that are obtained over the Western Atlantic. Hill (1952) and Katz and Ewing (unpublished manuscript) describe wide angle reflections obtained during the course of their seismic refraction measurements. More will be said about their results and conclusions later. This report is the first on a *detailed* seismic reflection profile over deep oceanic areas; one of the main conclusions is that the characteristics of the sedimentary column, principally the seismic velocities and thicknesses, can be determined by this method.

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Independent investigations have been carried out on this problem by J. Nafe and J. Ewing at Columbia and C. B. Officer at Woods Hole. The investigation by Nafe and Ewing, to be published soon, involves a broad areal coverage by sub-bottom reflection techniques, whereas this report contains a more detailed discussion of the sediment characteristics on the basis of a single profile.

## OPERATIONAL TECHNIQUES

A series of seismic reflection measurements were made during the summer of 1953 on a cruise of the research vessels *Atlantis* and *Caryn* from Woods Hole to Bermuda and return. The data were obtained over the continental slope, continental rise, abyssal plain, Bermuda rise, Bermuda slope, and Kelvin banks

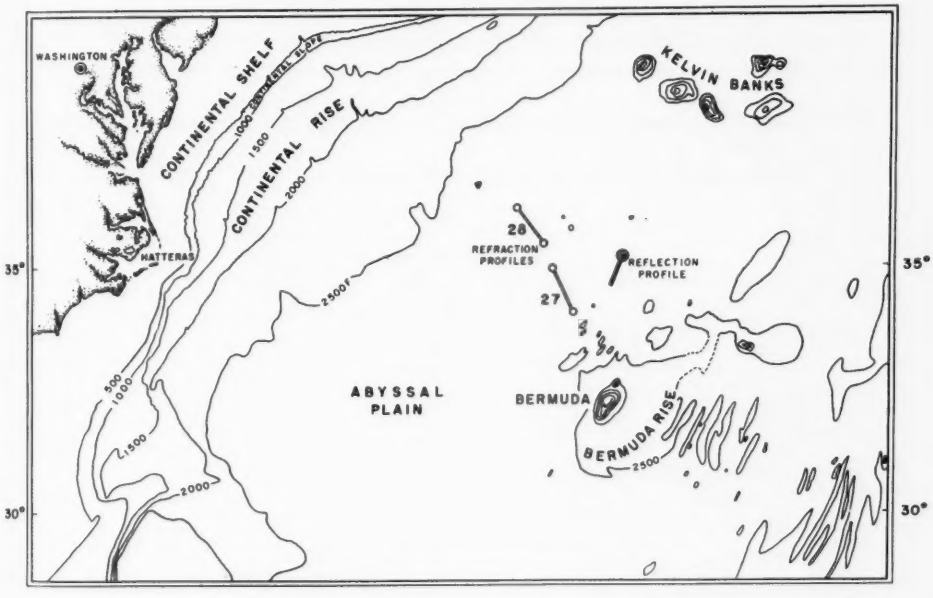



FIG. 1. Location of deep-sea seismic reflection profile.

(Fig. 1). This paper presents the results from one of the abyssal plain profiles; the same conclusions can be reached from the other profiles over this feature.

The method is similar to that for any two-ship seismic operation. The *Atlantis* recorded from a hydrophone at 50 ft and from another at 1,000 ft below the ocean surface. The ship was hove to, and all rotating machinery and other noise makers were silenced. The charges, fired from the *Caryn*, were one-half pound TNT-tetryl, and a balloon was tied to them by a piece of string so that they would fire at 2 feet below the surface. At this shallow depth the explosion gas bubble will not oscillate to complicate the sub-bottom reflection patterns and also will not break the surface and thus lose energy into the atmosphere. In this paper,

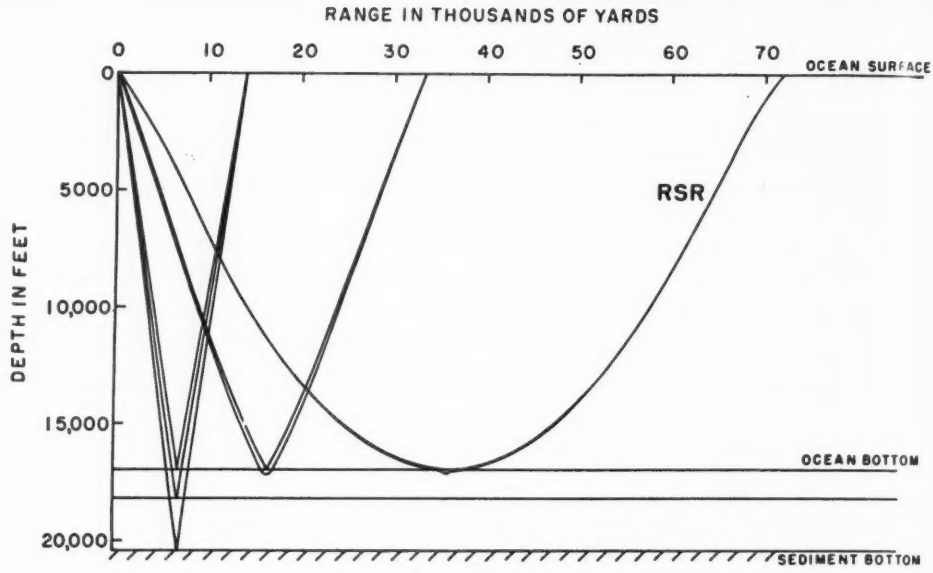
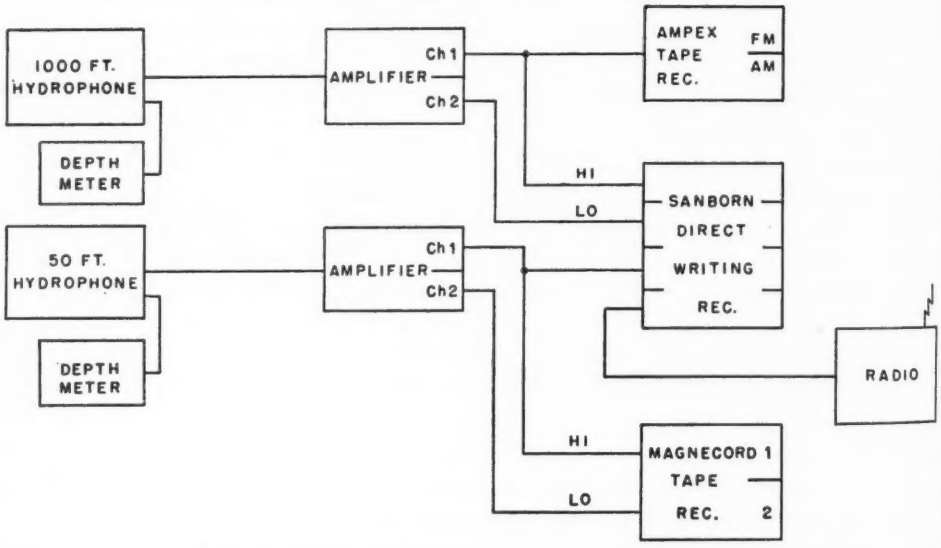



FIG. 2. Ray diagram of bottom and subbottom reflections and refractions.



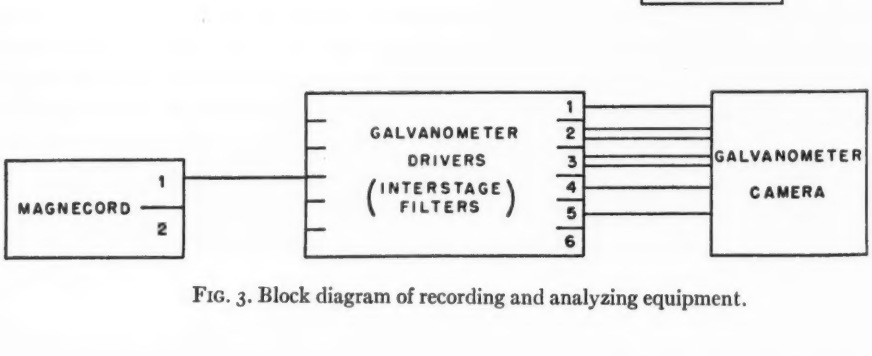




FIG. 3. Block diagram of recording and analyzing equipment.

only the recordings from the 50-ft hydrophone are presented, for these do not have the additional complication of arrivals reflected from the ocean surface back to the hydrophone as do the recordings from the phone at 1,000 ft. All recordings were taken on magnetic tape without the use of filters. The range was determined from the travel time of the direct arrival from shot to receiver guided in the small, 100-ft sound channel at the ocean surface (Fig. 8). This time interval was observed with a direct-writing recorder. The depth of water on this profile was 16,750 ft and shots were fired about every 500 or 2,500 yards along the

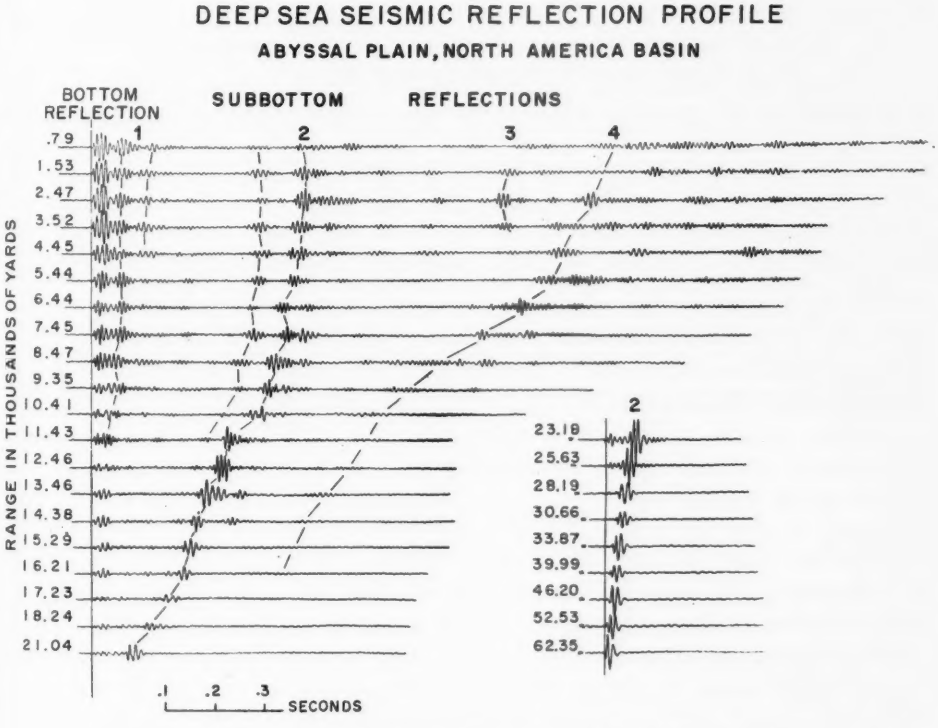



FIG. 4. Deep-sea seismic reflection profile, abyssal plain, 80–100 cps.

shooting ship's traverse until it was 100,000 yards from the recording ship. This distance was beyond the range at which energy is no longer received from a single bottom reflection, the limitation resulting from the sound velocity structure in the ocean (Fig. 2). The profile was not reversed.

In the laboratory the magnetic tapes were replayed through two-stage amplifiers and interstage variable-bandpass electronic filters into a galvanometer camera. Block diagrams of the original recording and analysis arrangements are shown in Figure 3 and sample records are shown in Figures 4 and 5. With the one-half pound near-surface shots, only frequencies down to 50 cps were excited.

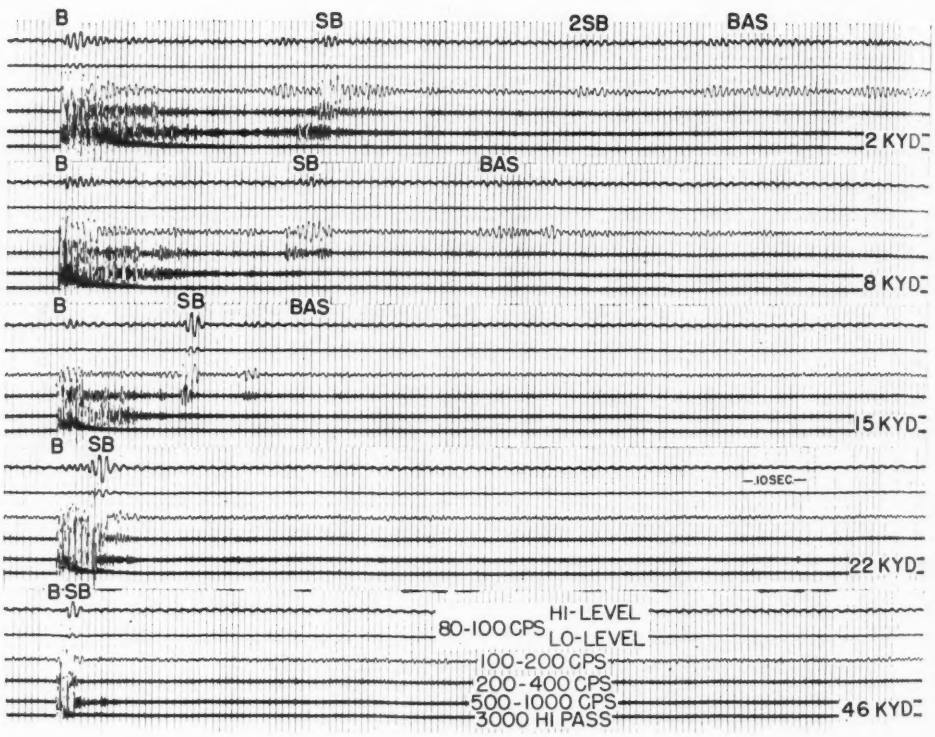



FIG. 5. Deep-sea seismic reflections as a function of frequency.

## REFLECTION DATA

There are many features of a deep-sea seismic reflection profile which can be seen directly on the records. The sub-bottom reflections are clearly observed at frequencies below 300 cps; there is little penetration by the higher frequencies. The sub-bottom reflections are quite clear and distinct and can be easily followed from record to record. They appear more distinctly at a long range than at near-vertical incidence. This is because the reflections approach their critical angles at the longer ranges. Further, the noise level between the groups of reflection events is low, indicating the presence of homogeneous material between the reflecting interfaces.

Four reflection groups are identified and can be followed from record to record. A group of reflections, marked (1) on Figure 4, at .04–.06 sec after the bottom reflection can be followed out to a range where it becomes difficult to resolve them from the bottom reflection. A second group of three reflections, marked (2), at .30–.50 sec are observed at the closer ranges. The middle one of these reflections can be followed for the entire length of the profile and is the most prominent and useful event. The multiple of this reflection, marked (3), is observed over a short range interval. A fourth reflection, marked (4), with a longer duration is observed

at 1.00–1.10 sec at the near ranges and can be followed out to 16,000 yards. This reflection is believed to come from near the bottom of the sediment. The noise level for about a second after this reflection is higher than that between the earlier reflections; after event (4) some other arrivals can be followed for a few records.

Considering the length of the spread and the distance between shots for this deep-ocean reflection profile, the correlation here must be between reflection groups rather than between particular cycles, as is done in oil exploration. This kind of correlation is not, of course, as refined as that employed in exploration and it requires a higher signal-to-noise ratio than can be tolerated with a closely spaced, multi-element spread such as is used in commercial prospecting.

A first interpretation of the data was made using average velocities through each column. This was adequate and accurate for the near-vertical reflections out to 15,000 yards. The sound-velocity structure in the ocean was determined from hydrographic stations and from bathythermograph lowerings. The latter measure the temperature as a function of depth for the variable near-surface water down to 900 ft. The sound-velocity structure of the deeper water is more stable, and the information for depths below 900 ft can be assumed on the basis of previous hydrographic data taken in the vicinity. The sound velocity in the ocean varied from a maximum of 5,050 ft/sec near the surface to a minimum of 4,890 ft/sec at 4,000 ft and increased to a maximum of 5,070 ft/sec at the bottom. The average vertical velocity was 4,960 ft/sec. In great depths of water it was expedient to plot the time differences between the sub-bottom reflections and the bottom reflections against range rather than the total travel time of the sub-bottom reflections. Theoretical curves have been computed for average sediment velocities, and those that gave a reasonable fit to the data are shown in Figure 6.

The velocity in the sediment to the first horizon at 100–150 ft below the bottom cannot be determined. Curves are shown for ratios between sediment and water velocities of 0.9, 1.0, and 1.1, and no one curve fits the plotted data better than the others. This would be expected in measuring a layer of this thickness from an elevation of 17,000 ft. The next reflection from a depth of 1,170 ft below the sea bottom, indicates an average veolcity of 5,460 ft/sec for the overlying sediment. This prominent reflector is found on all the deep-sea profiles examined to date, and the geological and geophysical significance of this discontinuity in the sediment column is an interesting question. The observed data points diverge noticeably from the theoretical curves beyond 30,000 yards; this is indicative of the fact that the overlying sediment has a varying rather than a constant velocity. Further, the fact that this sub-bottom reflection has not crossed the bottom reflection at grazing incidence indicates that the sediment velocity just below the ocean bottom must be lower than that of the overlying ocean water. The curve fitting the third reflection group is the multiple of the second.

The fourth reflection, from 3,350 ft below the bottom, indicates an average

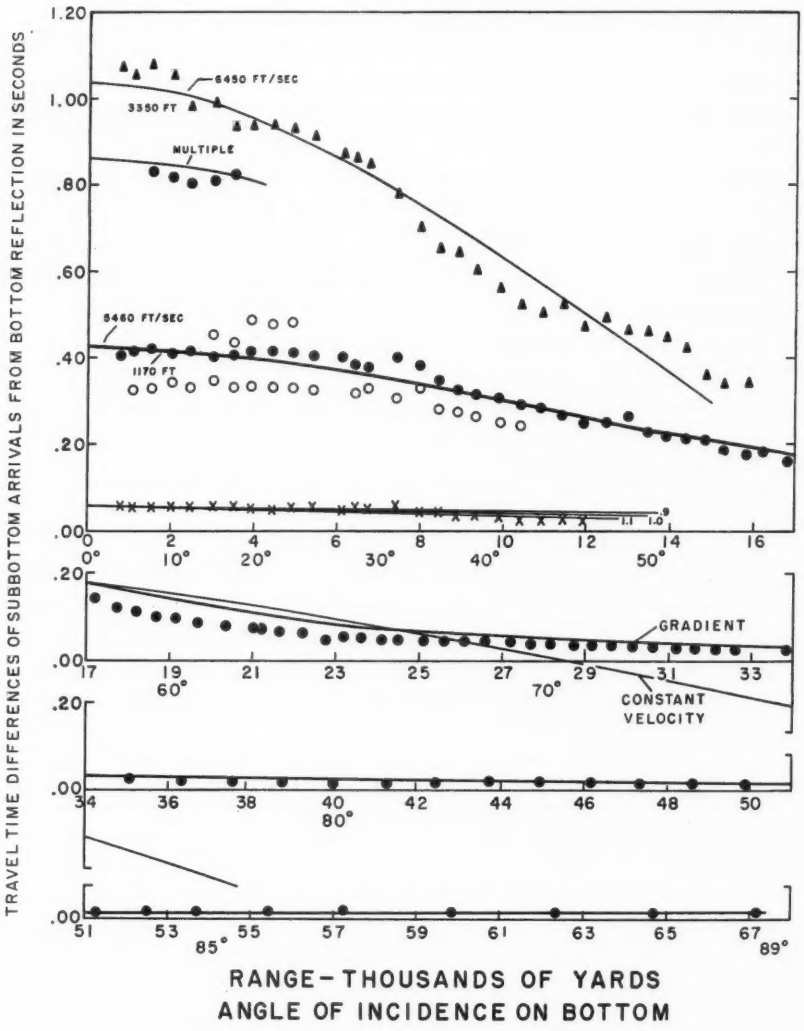



FIG. 6. Travel time graphs of subbottom reflections. Different symbols indicate times for various events correlated across parts or all of profile.

velocity from the ocean bottom to this depth of 6,450 ft/sec or an interval velocity from the depth of the second reflection to this depth of 7,150 ft/sec. This reflecting horizon is near the bottom of the sedimentary column, as determined from adjacent refraction profiles. Ewing, Sutton, and Officer (1954) report data from two refraction profiles in the same vicinity (Fig. 1): station 27 gave 3,950 ft of sediments and station 28 gave 4,300 ft.

The refraction measurements, such as those at stations 27 and 28, have all shown a high velocity basement underneath the sedimentary column in the deep

ocean basins. The velocity of this basement material is characteristic of basaltic rocks. The reflection profile measurements demonstrate that almost the entire sedimentary column is of low-velocity material and must be for the most part unconsolidated. It would be interesting to have an age scale through this column.

### DISPERSIVE SEDIMENT—LOW VELOCITY CONTRAST

One of the most interesting conclusions arrived at from this profile is the discovery that the deep-sea sediment is dispersive and, further, that at low frequencies the velocity in the sediment just below the bottom is lower than that in the ocean water just above the bottom. To begin, let us consider the theory of propagation in a gross mixture of sediment particles and water. For the static case, the velocity of propagation can be derived directly from fundamental principles (Heiland, 1940, pp. 474–475; Urick, 1947; and Chambré, 1954) and it can be written in the form

$$C_s = \sqrt{\frac{1}{(fm + f_1 m_1)(f\rho + f_1\rho_1)}}, \tag{1}$$

where $f$ and $f_1$ are the respective volume fractions of water and sediment particles, $m$ and $m_1$ are the compressibilities, and $\rho$ and $\rho_1$ are the densities. The porosity of the sediment is $f$. $m_1$ is generally much smaller than $m$, whereas $\rho_1$ and $\rho$ are of comparable size. Thus as the sediment mixture is built up, say from 100 percent water, the effect of adding sediment particles is first to load the mixture, therefore decreasing its sound velocity. As the porosity decreases, the effect of the compressibility term becomes important; and the velocity begins to increase. A hypothetical case is shown in Figure 7. The velocity contrast of sediment-mixture to water is plotted against porosity. At high porosity values of 0.7–0.8, the velocity of sound in the sediment can be as low as 0.97 that in water. Measurements of the porosity of deep-sea sediment by Kullenberg (private communication) give values ranging from 0.65 to 0.85. The porosity is generally high, and it is higher for the finer sediments, so that from theory alone one would expect that the velocity of sound propagation in deep-sea sediments should be lower than that in water.

For the dynamic case, one must introduce permeability, or viscosity, to account for the resisting effect of the water motion in the matrix of sediment particles. As the frequency is increased, the sediment begins to act more as a rigid body; and the velocity of sound propagation through it increases. Morse (1951) and Ament (1953) have derived an approximate theory for the dynamic case, and on the basis of Ament's treatment the velocity and absorption coefficient can be written in the following form for low frequencies:

$$C = C_s\left(1 + F^2\frac{8\pi^2 f f_1 r^4(\rho_1 - \rho)^2(f\rho_1 + f_1\rho)}{81\eta^2\rho_s}\right) \tag{2}$$

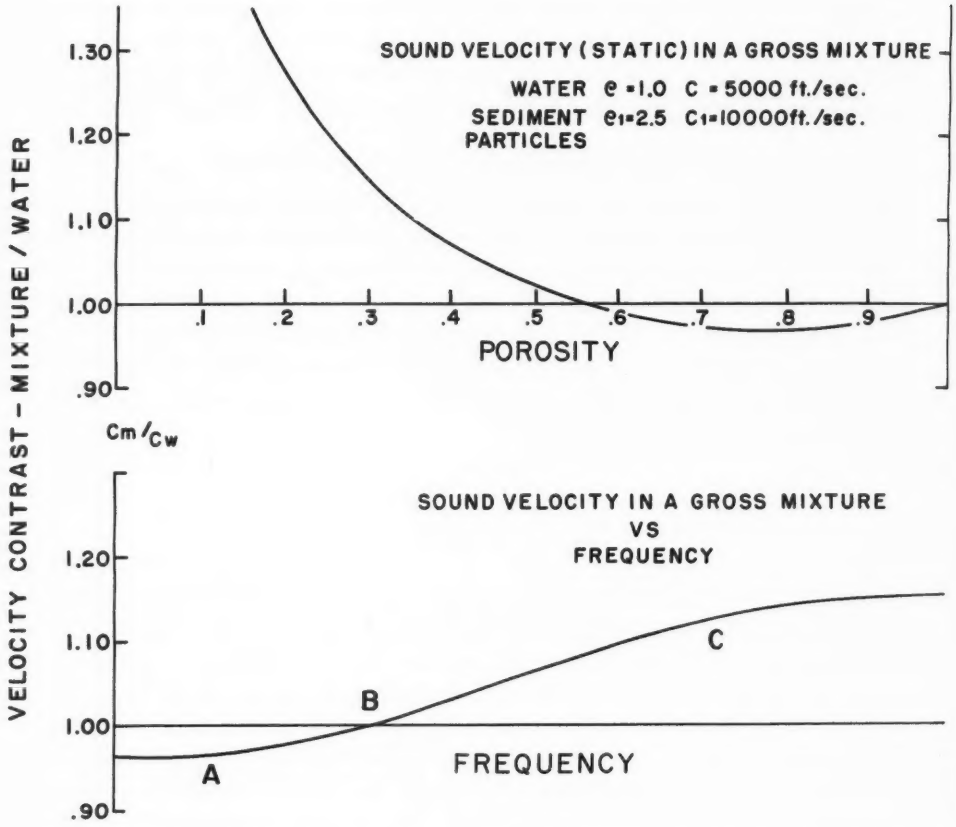



FIG. 7. Sound velocity as a function of porosity and frequency in sedimentary materials.

and

$$\beta = F^2 \frac{4\pi^2 f f_1 r^2 (\rho_1 - \rho)^2}{9\eta \rho_s C_s}, \tag{3}$$

where $C$ and $C_s$ are the dynamic and static velocities; $\rho_s$ is the static density, $f\rho + f_1\rho_1$; $F$ is the frequency in cps; $\beta$ the absorption coefficient; $\eta$ the viscosity; and $\gamma$ the radius of the sediment particles. It is difficult to specify numbers for $\gamma$ and $\eta$. The curve for equation (2) shown in the lower portion of Figure 7 has been drawn for an unspecified frequency scale. The radii of deep-sea sediment particles range from less than 1 micron to greater than 100 microns; Revelle (1944) has an excellent tabulation of these radii for Pacific deep-sea samples. To the author's knowledge, no values have been published for the viscosity or permeability of deep-sea sediments. For the case of a radius of 5 microns and a viscosity of $10^{-1}$ cgs units the velocity contrast would become greater than 1.0

at 2,700 cps; this is a higher frequency than is observed on our profile. The absorption would be 0.3 db per thousand yards at 100 cps and 30 db at 1,000 cps.

There are three ways in which a sediment with these properties should be observed from a deep-sea reflection profile. First, the energy reflected from the ocean bottom as a function of the angle of incidence should show a marked change from low frequencies, at which the bottom shows a low velocity contrast, to high frequencies, at which the bottom shows a high velocity contrast. The first-order theory for reflectivity can be taken from the Rayleigh reflection law. For sound reflected from a dicontinuity across which there is an increase in velocity, the reflectivity will increase from normal incidence to a value of unity at an intermediate angle, the critical angle. For angles of incidence greater than this the reflectivity remains unity. For sound reflected from a discontinuity across which there is a decrease in velocity, the reflectivity will decrease from normal incidence to zero at nearly grazing incidence. The reflectivity then rises rapidly to unity. Thus for frequencies in the range *A* of Figure 7, the reflectivity should decrease with angle of incidence and for frequencies in the range *C* it should increase to a critical angle. This is strikingly evident on the records of Figures 4 and 5. At the low frequencies, 75–150 cps, the bottom reflected energy decreases with range to a faintly observable level at the long ranges. At the high frequencies, 500–1,000 cps, the bottom reflectivity does indeed increase from normal to critical-angle incidence and remains uniform for increasing angles.

Second, for a dispersive sediment the travel times of the sub-bottom reflections should be a function of frequency. This can be seen on the records of Figure 4, particularly at the longer ranges; the higher frequencies of the prominent sub-bottom reflection arrive earlier.

Third, the travel times observed from the reflection profile should demonstrate that there is a low-velocity contrast. In fitting a constant velocity to the prominent second reflection group it was observed that there was poor agreement at the longer ranges, indicating that there must be a gradient in the sediment; moreover, since the sub-bottom reflection had not crossed the bottom reflection at grazing incidence, the velocity in the sediment near the ocean bottom must be lower than that in the adjacent ocean. Consideration of the sound-velocity structure in the ocean alone will not resolve this discrepancy.

Of the simple velocity gradients which might be used for calculation, a parabolic gradient was chosen *a priori*. The velocity at the top of the sedimentary column was chosen to be 0.97 times that of the water at the sea bottom, or 4,920 ft/sec. The gradient was calculated from the observation at close ranges that the average vertical velocity to the horizon at 1,170 ft below the bottom was 5,460 ft/ sec. The final equation is

$$v = 4{,}920(1 + 4.17 \times 10^{-4}\, z)^{1/2}, \qquad (4)$$

where $v$ is the velocity in ft/sec and $z$ the depth in ft below the bottom. The velocity at the bottom of the column would be 6,000 ft/sec. This velocity gradient

gave a good fit to the data over the entire range of reception. The reflection becomes a refraction at a range of about 10,000 yards and at ranges beyond 40,000 yards it is penetrating 250 ft or less of the sediment. The porosity can be computed as a function of depth from equations (4) and (1), and it is plotted along with the sound velocity section of Figure 8; this curve should give the correct order of magnitude of the decrease of porosity with depth but it cannot give the exact shape of the curve or reliable values of porosity at a particular depth. Hill (1952) recorded this sub-bottom refraction at intermediate ranges on a series of seismic refraction profiles in deep water off the coast of Ireland. He concluded

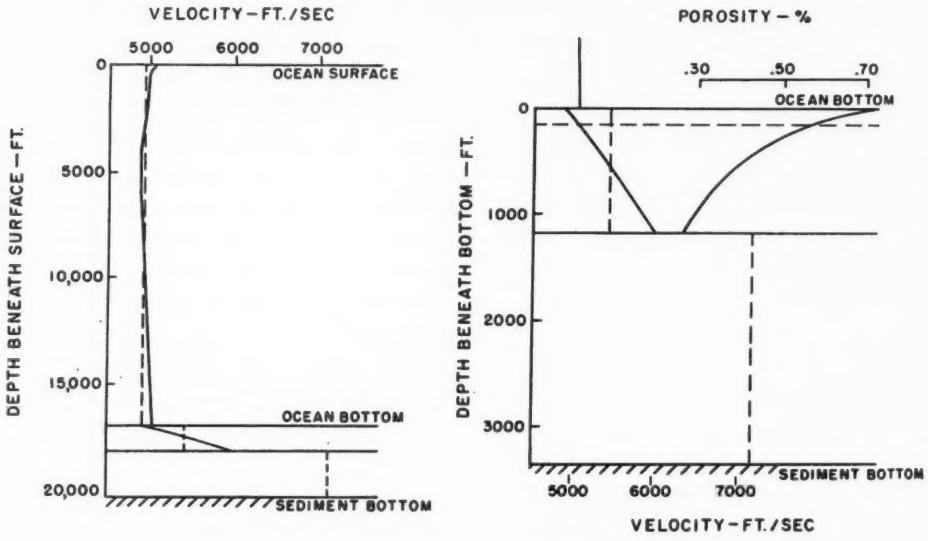



FIG. 8. Sound velocity and porosity sections.

as here, that the arrival was a refraction in the sediment. His measurements were taken at low frequencies, and he did not record the bottom reflection itself.

All three of these observations form a clear geophysical demonstration that the deep-sea sediment is dispersive and that its upper portion has a velocity lower than that in water.

## WAVE GUIDE—LOW VELOCITY LAYER

In one of the early deep sea seismic refraction measurements, Hersey, Officer, Johnson, and Bergstrom (1952) reported a single-frequency forerunner which appeared beyond the range at which the first bottom reflection arrival should be received. At this range, the first bottom reflection becomes a refraction at depth in the ocean, following the path of the RSR rays of Ewing and Worzel (1948); at greater ranges it is transmitted by leakage from the surface sound channel and RSR paths. From its travel time plot, the single-frequency forerunner was

interpreted as a wave which travelled over a portion of its path near the ocean bottom, travelling to and from the bottom by the RSR path which was grazing at the bottom. It was not possible to state from the physical data then available whether the wave travelled in the bottom water or in the sediment, but it was felt that in order for such an arrival to exist and to have the single frequency characteristic, there must be trapping of energy near the bottom in a wave guide. Such trapping would take place by a coupling process such as that proposed by Lamb (1932, p. 413–415) and extended by Press and Ewing (1951) and Jardetsky and Press (1952) to particular geophysical cases. According to this mechanism, a disturbance travelling across a boundary in an extended medium, the ocean, will couple to a low-velocity layer, the sediment, at the frequency for which the phase velocity in the sediment is equal to the velocity of sound in the extended medium. This will give reinforcement at all points on the boundary.

Subsequently Katz and Ewing (unpublished manuscript) observed the same phenomenon and arrived at the same conclusion. They were able to show that the frequency is determined by local conditions and that it is not related to the depth of water. Assuming a low-velocity section in the sediment, for which they had indirect evidence from shallow water measurements by others, they showed that the thickness of this section varied from 50 ft to 150 ft over the range of observed forerunner frequencies, which was from 30 to 100 cps. The velocity contrast for the section was taken to be 0.98.

In the results reported in this paper, we have *direct* evidence that there is a low-velocity sedimentary layer, which should be excited as a coupled wave guide for ranges beyond which the RSR ray travels across its surface at grazing incidence. The thickness of the low-velocity section as computed from the frequencies of the coupled wave is in agreement with that indicated in Figure 8 on the basis of the seismic reflection profile.

## ACKNOWLEDGMENTS

The author wishes to express his thanks to Dr. J. B. Hersey for cooperation and helpful discussions during this investigation, to Messrs. Johnson, Bergstrom, and Duys and Drs. Dietz and Wheeler for their cooperation in the scientific work at sea, and to Capts. Bray and Karlson and the crews of the research vessels *Atlantis* and *Caryn*. This work was done under contract Nobsr 43270 with the Bureau of Ships, U. S. Navy.

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GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955), PP. 283–294, 5 FIGS.

# CHANNEL WAVES IN THE EARTH'S CRUST*

B. GUTENBERG†

## ABSTRACT

Three major low-velocity layers seem to exist in the earth's crust, of which two, the lithosphere channels, are found respectively in the "granitic" and "basaltic" ("gabbro") layers of the continents; a third channel extends from the Mohorovičić discontinuity downward into the asthenosphere. Several types of waves are guided by these channels, especially *Pa* and *Sa* by the asthenosphere channel, *Lg1*, *Lg2* and *Rg* by the lithosphere channels; waves guided by low-velocity layers in sediments must also be expected. Many records of the Southern California earthquake of July 21, 1952 show channel waves with periods and velocities as reported for other paths. The regular microseisms with periods of 4 to 10 sec have properties similar to those of the *Lg*—*Rg* group in earthquake records and are probably propagated by the same mechanism.

Most of these interpretations and conclusions are tentative; pertinent observations are scanty; and complications have thus far prevented development of adequate equations to calculate the amplitudes of waves guided by a given channel.

## INTRODUCTION

The terms "channel wave" or "guided wave" indicated originally a body wave which, according to the classical ray equation based on Snell's law, is travelling completely inside a low-velocity layer (for example, *Lg2* in Figure 4). Frequently, surface waves which are appreciably affected by a low-velocity layer situated within a few wave lengths below the surface are also called channel waves. In the present paper this wider use of the expression "channel waves" is employed, especially since it is not yet certain which of the waves under consideration are body waves and which are surface waves. To a first approximation, the classical theory for surface waves is applicable to crustal structures which include a low-velocity layer. However, special theoretical investigations with better approximations are needed for the discussion of, and especially for the calculation of amplitudes for, channel waves of the body-wave as well as of the surface-wave types.

From various observations of amplitudes and travel times of body waves, Gutenberg (1954, with references to earlier papers) had concluded that there are at least two groups of low-velocity channels in the earth's crust. Above the Mohorovičić discontinuity are the "lithosphere channels" (see Figure 4, left) consisting probably of one channel in the so-called granitic layer,[1] another in the

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[1] The so-called granitic layer probably includes rock types differing appreciably from granite, possibly even basalt, and may be subdivided by discontinuities (see, e.g., Gutenberg, 1955). The layer below it extending downward to the Mohorovičić discontinuity is called basaltic layer by some, gabbro layer by others. Below the Mohorovičić discontinuity begins the "mantle" ("ultra-sima"). The lithosphere is the relatively strong outer part of the crust, the asthenosphere the deeper part where flow processes are supposed to make possible restoration of isostatic equilibrium.

"gabbro" layer; below the Mohorovičić discontinuity is the "asthenosphere channel," extending downward to a depth of about 150 km for longitudinal waves and to about 250 km for transverse waves (Gutenberg, 1955). Detailed investigation of these low-velocity layers is rendered difficult since their main effect consists in production of shadow zones. They were first suspected when it was observed that at certain distances the supposedly direct longitudinal or transverse waves arrive with very small amplitudes, also when conclusions based on various types of studies were found to contradict each other when observations were interpreted on the assumption that no low-velocity layer exists. The channel waves discussed in the present paper are among the rare instances of observable waves which are a consequence of low-velocity layers.

Press and Ewing (1951, 1952) have discovered two types of guided waves traveling in the "granitic" layer of North America, and have started the investigation of channel waves which will probably play an increasing role in the interpretation of records of earthquakes and of artificial explosions. Press and Ewing find that one type of the waves, *Lg*, has periods of 1 to 10 sec and a velocity of 3.5 km/sec, while the other, called *Rg* by them, which has periods of 8 to 12 sec, travels with an average velocity of 3.0 km/sec. Lehmann (1953), and Ewing, Press, and Oliver (1954) have extended these results. Detailed observations for Eurasia are reported by Båth (1954). He comes to the conclusion that *Lg* consists of at least two different wave types, *Lg1* and *Lg2*, and agrees with Gutenberg (1954) that the lithosphere channels make possible their propagation. Prevailing periods in Uppsala are 3 to 8 (occasionally 2 to 11) sec for *Lg1*, 3 to 12 sec for *Lg2*, and 3 to 14 (occasionally 16) sec for *Rg*.

Two additional types of channel waves not related to the preceding were first found by Caloi (1953) on records of earthquakes with focal depths of the order of 100 km. He called one *Pa* (periods between 5 and 12 sec, velocity about 7.9 to 8.0 km/sec), the other *Sa* (periods 10 sec or more, occasionally up to 30 sec, velocity about 4.4 km/sec). Press and Ewing (1954) have found these waves independently and have explained them as *Pn* and *Sn* waves with "numerous multiple reflections at near-grazing incidence from the underside of the Mohorovičić discontinuity, in direct analogy with the whispering gallery effect discussed by Rayleigh." However, the fact that Caloi, Press, and Ewing (1955) and the author have observed them in shocks with intermediate focal depth is in favor of Caloi's explanation (given independently by Gutenberg in a discussion of the results by Press and Ewing, 1954) that they are waves guided by the asthenosphere low-velocity channel which had been established earlier.

The question has been raised if sufficient energy from waves in channels at some depth below the earth's crust can be observed at its surface. The waves *Lg* and *Rg* through the lithosphere channel with its upper boundary at a depth of the order of 10 km have usually periods of 3 to 8 sec and a velocity of $3\frac{1}{2} \pm$ km /sec, resulting in wave lengths of the order of 10 to 25 km, so that the earth's surface is roughly one wave length or less above the boundary of the channel.

The same holds for the *Sa* waves through the lithosphere channel with its boundary probably 40 or 50 km below the surface, since these waves have periods which are usually between 10 and 20 sec and a velocity of about 4½ km/sec. For sound waves through the main channel in the ocean, large amplitudes have been observed under similar circumstances, and elastic (sound) channel waves through the ocean as well as through the atmosphere have been generated by sources close to but outside the channel.

In the present paper, findings concerning various channel waves are discussed on the basis of records of the main Kern County, California earthquake of July 21, 1952, 11h 54m 14s, of some Pasadena records from other shocks, and of results published by various authors (see references).

## TRAVEL TIMES AND VELOCITIES OF WAVES GUIDED BY THE LITHOSPHERE CHANNELS (*Lg*, *Rg*, $\bar{S}$)

At relatively short distances, the various waves guided by the lithosphere channels can rarely be studied in detail on records of short-period instruments as a consequence of their large amplitudes and of other phases with short periods which are superimposed. On the other hand, long-period instruments emphasize the long-period surface waves arriving at about the same time. Consequently, *Lg*-waves are usually clearest when recorded on medium-period instruments where, frequently, they are riding on top of longer surface waves (Figure 1).[2] On the records of the 1952 California earthquake written at Guadalajara and Puebla, which were marked for Figure 1 before the results of Båth (1954) were known, the "*eLg*" corresponds to *Lg1* of Båth, the "*Lg*" to his *Lg2*. In the other records of Figure 1, the phase marked "*Lg*" is his *Lg1*.

Arrival times of *Lg1* were established on seismograms of the main 1952 shock at 17 stations, all on the North American continent, except for Kingston, Jamaica. The times for the latter fit well, but the recorded motion may belong to some other phase. However, no *Lg*-waves were found at other stations outside of the North American continent. Since there is some doubt whether or not the large short-period "*iM*" phases observed at distances between 10° and 14° in the 1952 California shock are *Lg* waves, two least square solutions were made, one with inclusion of four such instances, the second without them. The resulting equations for the travel time $t$ of *Lg1* to the epicentral distance $\Delta$ (measured in km) are:

All data: $$t = (4.6 \pm 4.9) + \Delta/(3.58 \pm 0.02) \quad (1)$$

Only $\Delta > 15°$: $$t = (9.5 \pm 10.0) + \Delta/(3.60 \pm 0.04). \quad (2)$$

Since the two equations agree within the limits of error, it is not unlikely that the short-period "*iM*" at distances of about 10° is actually *Lg1*. Observations of travel times of *Lg1* (zero line given by $t = 4 + 31\,\Delta°$ to permit use of a large scale) are plotted in the upper part of Figure 2, together with straight lines representing

[2] Figures have been arranged and drafted by Mr. J. Nordquist.

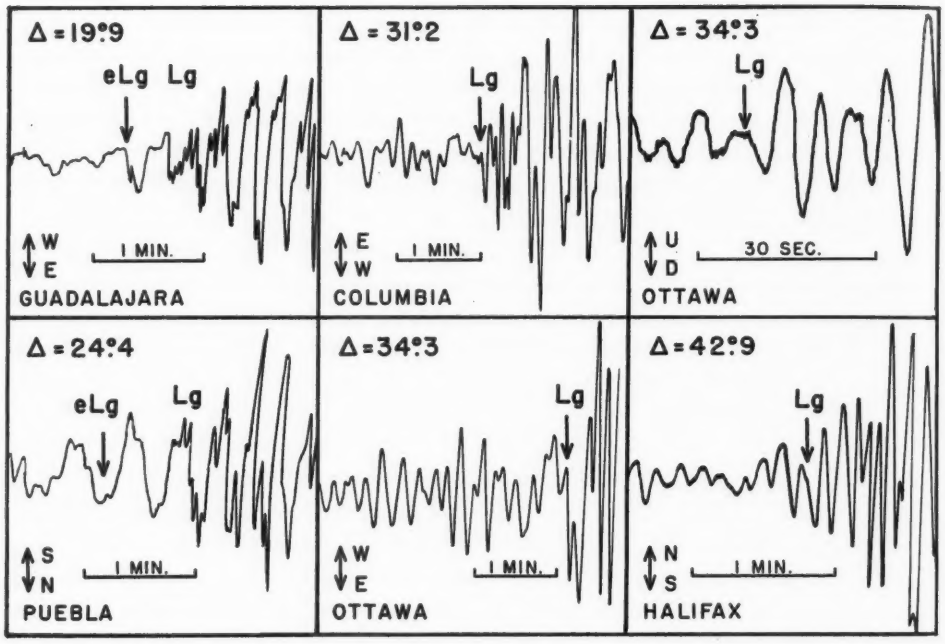


FIG. 1. Portions of selected records of the main Kern County, California, earthquake of July 21, 1952, showing *Lg* waves. Δ is the epicentral distance in degrees. Arrows indicate direction of ground motion.

equations (1) and (2). The velocities of $3.58 \pm 0.02$ km/sec (equation (1)) and $3.60 \pm 0.04$ km/sec (equation (2)) agree with those found by Press and Ewing ($3.51 \pm 0.07$), by Lehmann (3.57), and by Båth ($3.54 \pm 0.07$), especially if the effect of the constant term used in equations (1) and (2) is considered. The velocity of transverse waves near the top of the "granitic" layer in Southern California is $3.67 \pm$ km/sec (Gutenberg, 1951, p. 145).

The phase called $\overline{S}$ or *Sg* at epicentral distances over $150 \pm$ km (but not at distances less than $120 \pm$ km where it is the direct transverse wave indicated now by *s*) is possibly *Lg*. On seismograms recorded in Southern California at distances between about 150 and 500 km, "the phase previously called $\overline{S}$ corresponds roughly to the beginning of the maximum in the *S* group. . . . It seems to move to later and later phases as the distance increases" (Gutenberg, 1951, p. 161). This group creates "the impression of waves traveling in a dispersive medium" and has been considered to be a wave guided by a low-velocity channel. At distances of about 300 km, a phase of the $\overline{S}$-group, called *Se*, is usually the dominant $\overline{S}$-phase in seismograms written in Southern California, but at distances beyond about 500 km, another, called *Sf*, carries the largest amplitudes. The travel time curves of these two waves are given (*l.c.*, p. 161) by

$$Se: \quad t = 4.9 + \Delta/3.64 \qquad Sf: \quad t = 4.3 + \Delta/3.52. \tag{3}$$

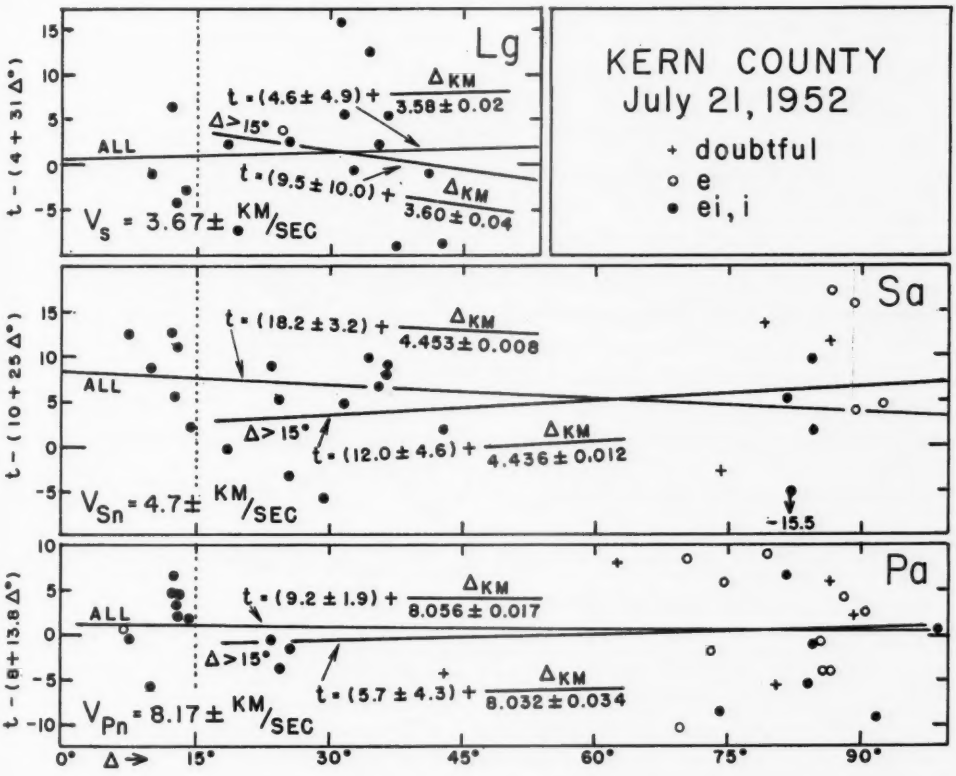


FIG. 2. Observed travel times $t$ of *Lg*, *Sa*, and *Pa*. Quantities $a+b\Delta$ are subtracted from $t$ to enable the use of a large time scale. The values of the constants $a$ and $b$ differ for each phase. $\Delta$ is the epicentral distance in degrees. Straight lines correspond to least-square solutions discussed in the text.

The velocities of *Se* and *Sf* agree well with those found for *Lg1* and, at distances of a few degrees, the $\overline{S}$-group may be identical with the *Lg*-group; the phase "*iM*", mentioned above for the 1952 California shock, may be the continuation of the $\overline{S}$-group at distances of about 10°.

Since there are not sufficient travel times for *Lg2* from records of the 1952 California shock to justify inclusion of a constant term in a solution using the method of least squares, it was assumed that the constant term is zero. The resulting velocity is:

$$v = 3.38 \pm 0.03 \text{ km/sec.} \qquad (4)$$

The velocity found by Båth for *Lg2* in Eurasia is $3.37 \pm 0.04$ km/sec.

Relatively few *Rg* waves can be identified on records of the 1952 California shock, partly as a consequence of the large motion, and most of the identifications are doubtful. The velocity of *Rg* found by Press and Ewing is $3.05 \pm 0.07$ km/sec, and that calculated by Båth is $3.07 \pm 0.04$ km/sec. Båth (1954, p. 303) points out

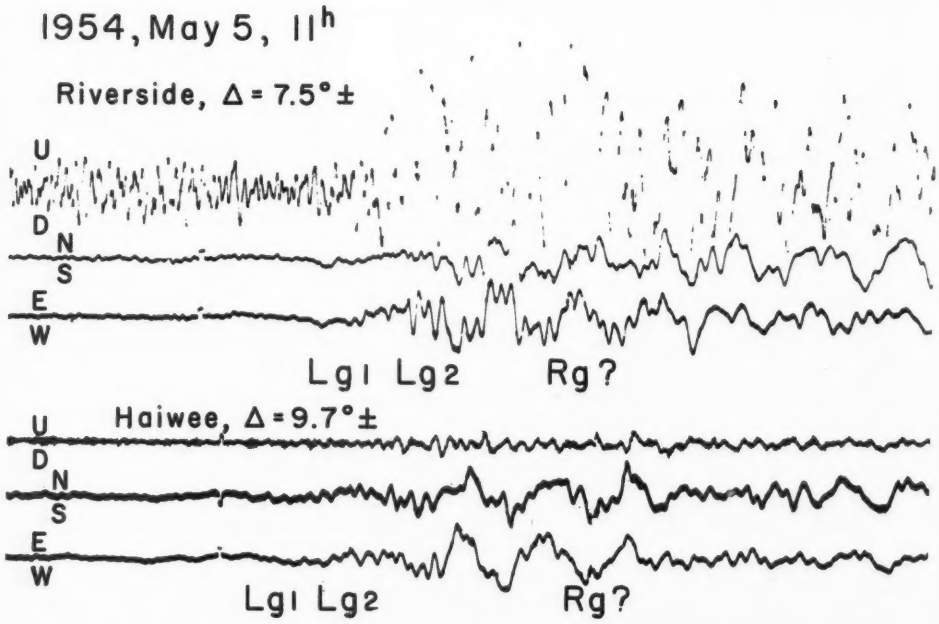


FIG. 3. Portions covering about 2½ minutes of seismograms recorded at Riverside and Haiwee, California, from an earthquake which originated approximately at 27° North Lat., 112¾° West Long. (Lower California). Instruments: Benioff short-period vertical seismographs (U-D) and horizontal standard Wood-Anderson torsion seismographs (N-S; E-W). Δ is the approximate epicentral distance in degrees. Since the epicenter is to the SSE of the stations, waves of the *SH* type should be recorded in the same direction on both horizontal components, *SV* and *P* in opposite directions. *Lg* and *Rg* have relatively short periods; long-period waves are surface waves.

that the observed velocities of *Rg* scatter more than those for both *Lg* waves, and that *Rg*, too, may consist of two or more wave types.

The *Lg*-waves have been tentatively considered to be transverse waves with a prevailing *SH* component. However, Press and Ewing (1952, p. 221) state: "During the first few cycles the waves have approximately equal amplitudes on all three components, but the transverse horizontal rapidly gains amplitude . . . within about 30 seconds," and Miss Lehmann (1953, p. 249, 251) points out that the waves have a considerable vertical component. Båth (1954, p. 316) finds that at Uppsala and at Kiruna the vertical component of *Lg* is smaller than the horizontal. Since few stations recording *Lg* in the California shock of 1952 had two horizontal components with approximately the same constants, some Pasadena records of other shocks have also been investigated. Figure 3 shows two examples: the horizontal seismographs have about the same constants; however, the vertical records are written by seismographs with appreciably different characteristics.

From all records which have been studied, it follows that in *Lg*, motion per-

pendicular to the ray (*SH* type) prevails, but that not infrequently an appreciable vertical component is recorded; in portions of *Lg*, the motion is approximately in the direction of the ray (*SV*-type). Some irregularities may result from body or surface waves superposed upon *Lg*. Otherwise, motion consisting of a shear in the horizontal component accompanied by a relatively large vertical component is not predicted by the classic wave theory for either body or surface waves.

### MECHANISM FOR TRANSMISSION OF THE *Lg*- AND *Rg*-GROUP

In a discussion of the mechanism for the transmission of *Lg*, Båth (1954, p. 321) states that not only the velocities but also their different relation to focal depth indicate that *Lg2* belongs to a lower layer than *Lg1*. He finds that in Sweden the *Lg2*-waves show a maximum energy (relative to *S*) for shocks originating at a depth of the order of 40 km, while the relatively largest *Lg1* waves are recorded for shocks with a focal depth of 20 km or less. He considers the possibility that *Lg1* is a wave travelling completely above the depth with maximum velocity (that is, roughly in the uppermost 10 km) with many reflections at the earth's surface, and that *Lg2* is a wave travelling in the low-velocity channel, that is at depth between roughly 10 and 20 km. However, he points out correctly (l.c., p. 322) that for foci below the level of maximum velocity, that is, for foci deeper than roughly 10 km, *Lg1* could then not exist if the classical wave theory holds, but that diffraction and scattering may be the mechanisms actually responsible.

The conclusion of Båth that *Lg2* seems to be propagated in a lower layer than *Lg1* seems to be doubtful, especially since the determination of focal depths in intervals of 10 km near a depth of 50 km (partly by Gutenberg and Richter) is not accurate enough for finding the relationship between focal depth and relative amplitudes of the phases from relatively few records of shocks supposedly slightly deeper than normal. On the other hand, use of the velocity ratio between *Lg* and *Rg* requires better knowledge of the wave types involved than we have now. Clues concerning the wave types may result from Båth's findings that the energy ratios *Lg2*/*S* and *Lg2*/*Rg* decrease with increasing magnitude, and that for shocks of a magnitude greater than 5 more energy passes into *Rg* waves than into *Lg2* waves, and more into *Lg2* than into *Lg1* waves.

Gutenberg (1954, 1955) has concluded that the hypothetical "gabbro" layer between the Conrad and the Mohorovičić discontinuities may be another low-velocity layer (Figure 4, left). The average velocity reported for this layer in a few regions on the basis of records of artificial explosions is roughly 3.8 km/sec (Gutenberg, 1955) and corresponds probably to the top of the layer. In Figure 4 some possible types of paths of *Lg* waves are sketched. The mechanism shown in the diagrams explains the long duration of the *Lg* group. The actual distribution of wave velocities with depth may differ appreciably from that indicated in Figure 4 which had been assumed on the basis of amplitude and travel time studies before the existence of *Lg2* was known. If these velocities and their changes

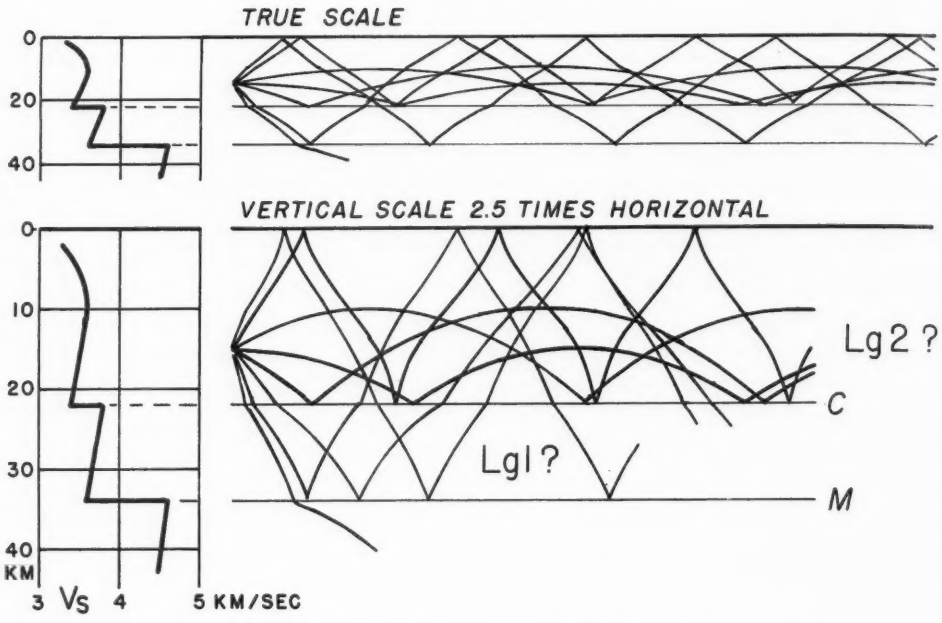


FIG. 4. Selected paths of transverse channel waves, constructed on the basis of the assumed velocity *Vs* of transverse waves as a function of depth, given at the left. *C* = Conrad discontinuity between "granitic" and "gabbro" layers. *M* = Mohorovičić discontinuity separating the latter from the ultrabasic mantle.

with depth are a good approximation to the actual values, it seems likely that *Lg2* is a true channel wave along the channel in the "granitic" layer, while *Lg1* in addition possibly enters the channel in the "gabbro" layer. The various types of paths can not be constructed with confidence before the velocities are better known as a function of depth.

The observed relative importance of *SH* (dominant), *SV*, and *P* (negligible) in these channel waves corresponds to the fact that total reflection is most likely for *SH*, less so for *SV*, and still less for longitudinal waves. The following is a summary of the conditions for total reflection at the earth's surface and at a discontinuity, where $r$ = ratio of transverse velocity above to transverse velocity below; $r$ is assumed to be between 0.6± and 1.0:

| | *SH* | *SV* | longitudinal |
|---|---|---|---|
| surface | always | $i > 35° \pm$ | never totally reflected |
| discontinuity | $i >$ arc sin $r$ | $i >$ arc sin $r$ | never totally reflected |

There is little disagreement about *Rg*. Båth (1954, p. 307) points out that it shows dispersion of a type found theoretically by Haskell (1951) for Rayleigh

waves propagated through surface layers including a low-velocity layer. At present, the conclusion that *Rg* is such a Rayleigh wave is preferred by all who have studied it.

## EFFECTS OF THE STRUCTURE OF THE EARTH'S CRUST ON *Lg*-WAVES. MICROSEISMS

Below the ocean basins the "granitic" layer is usually missing, and the "gabbro" layer extends only to a depth of 10 ± km below sea level. Consequently, there is probably no decrease in velocity with depth in the ocean bottom above the Mohorovičić discontinuity, especially since such a decrease would begin at a greater depth under the oceans than under the continents as a consequence of the lower temperature under the oceans. Therefore, no *Lg* or *Rg* waves can be expected with a path across an ocean bottom—if our explanations for their mechanism are correct. Actually, all authors agree that neither *Lg* nor *Rg* waves with paths through the crust under the deeper parts of ocean are observed. In addition, *Lg* and *Rg* waves are weakened or even disappear in crossing recent mountain chains, where probably the channels are too much distorted to permit transmission of guided waves (Båth, 1954, p. 300, 319; Ewing, oral communication). In California they seem to be more weakened in crossing the transverse ranges and the Sierra Nevada than along paths between Mexico and Southern California.

Gutenberg (discussion of the paper by Båth, Rome, 1954) has pointed out that in many respects the properties of the regular microseisms with periods of 4 to 10 sec show great similarity to those of earthquake waves guided by the lithosphere channel. This includes especially their velocity of about 3 km/sec, their periods, and the "barriers" to their propagation in bottoms of deep oceans and under young mountain chains. All recent results are in favor of the hypothesis (Gutenberg, 1954) that these microseisms are due to waves guided by the lithosphere channels.

## THE PROBLEM OF $\overline{P}$ AS A CHANNEL WAVE

There is some doubt about the existence of longitudinal waves guided by the lithosphere channel, similar to the *Pa*-waves guided by the asthenosphere channel. The group of longitudinal waves including $\overline{P}$ and the following first motion in seismograms recorded at distances beyond about 150 km was the first which was suspected to be guided by the low-velocity channel in the lithosphere (Gutenberg, 1951, p. 162). In Southern California, the amplitudes in the $\overline{P}$-group have a maximum at a distance near 130 km, and then decrease about exponentially to a distance of at least 500 km, where for a shock of magnitude 7.6 the ground amplitudes of such waves with periods of the order of 1 sec should be roughly 100 microns on the basis of a study of many smaller shocks. Only very few seismograms of the California shock in 1952 at distances beyond about 8° [for shorter distances all amplitudes are too large] show waves possibly belonging to this group. Their amplitudes continue to decrease rapidly with the distance, and near

20° the ratio of their amplitudes to the period does not exceed 3±. This agrees with the findings by Båth (1954, p. 316) that at greater distances there is no indication of longitudinal waves guided by the lithosphere channel.

The velocity of "$\overline{P}$" in Southern California and in other regions has been found to be 5.6± km/sec. However, the maximum of the amplitudes moves gradually from one phase of the group to another. The group creates "the impression of waves travelling in a dispersive medium." (Gutenberg, 1951, p. 162), and the observed velocities are probably group velocities, which could differ from the phase velocity since the periods increase noticeably with distance (Gutenberg, 1936).

### WAVES GUIDED BY THE ASTHENOSPHERE CHANNEL (*Pa* AND *Sa*)

The seismograms of the Kern County shock include only a few written at distances between about 45° and 70°. This explains the gap in the data (Figure 2) for these distances. In addition, *Pa* arrives close to *PP* at distances of between about 25° and 40°, and should be close to *SKS* or in the *SKKS*-group beyond about 100°, which limits the use of records in these ranges of distances for *Pa*. On records of the Kern County shocks, *Pa* is usually less definite than *Lg* or *Sa*. Thirty-three instances of *Pa* were found, of which 24 are at distances beyond 23°. At distances between 7° and 15°, the large longitudinal phase following the beginning of the record was measured. Again, two least square solutions were made, one including all data (minimum distance 7°), another for the phases arriving at distances greater than 23°. The following travel times result:

All data: $t = (9.2 \pm 1.9) + \Delta/(8.056 \pm 0.017)$ (5)

$\Delta > 23°$ only: $t = (5.7 \pm 4.3) + \Delta/(8.032 \pm 0.034)$. (6)

Residuals are shown in Figure 2 (bottom). Since constants in the two equations agree within the limits of error, the large longitudinal phase near the beginning of records at distances between 7° and 15° may be produced by the same mechanism as $\overline{P}a$ at greater distances. Press and Ewing find that their "*Pn* at great distances" has about the same velocity as *Pn* at short distances (8.1±km/sec); Caloi finds velocities between 7.9 and 8.0 km/sec for his *Pa*.

In the records of the California shock of 1952, *Sa* is frequently rather clear (Figure 5). Its forms and periods are similar to those reproduced by Caloi (1953) for *Sa*-phases in shocks originating at intermediate depth. Since *Sa* is recorded near *SS* at distances of 30° to 40° ,and at greater distances is superimposed on the long surface waves, it is best found on medium-period instruments. At distances near 15±°, the arrival time of the frequently rather large transverse phase, following the expected *S* by roughly 20 seconds (depending on the distance) was measured on records of six stations. In addition, *Sa* was found on records of twenty-two stations at distances between 18° and 93°. The method of least squares gives the following travel times:

All data: $t = (18.2 \pm 3.2) + \Delta/(4.453 \pm 0.008)$ (7)

$\Delta > 18°$ only: $t = (13.0 \pm 4.6) + \Delta/(4.436 \pm 0.012)$. (8)

Residuals are shown in Figure 2 (center). The velocity of *Sn*, which probably travels near the top of the asthenosphere channel, seems to be about 4.7 km/sec (Gutenberg, 1954). Caloi as well as Press and Ewing find a velocity of about 4.4 km/sec for *Sa* (without assumption of a constant term). Caloi points out that

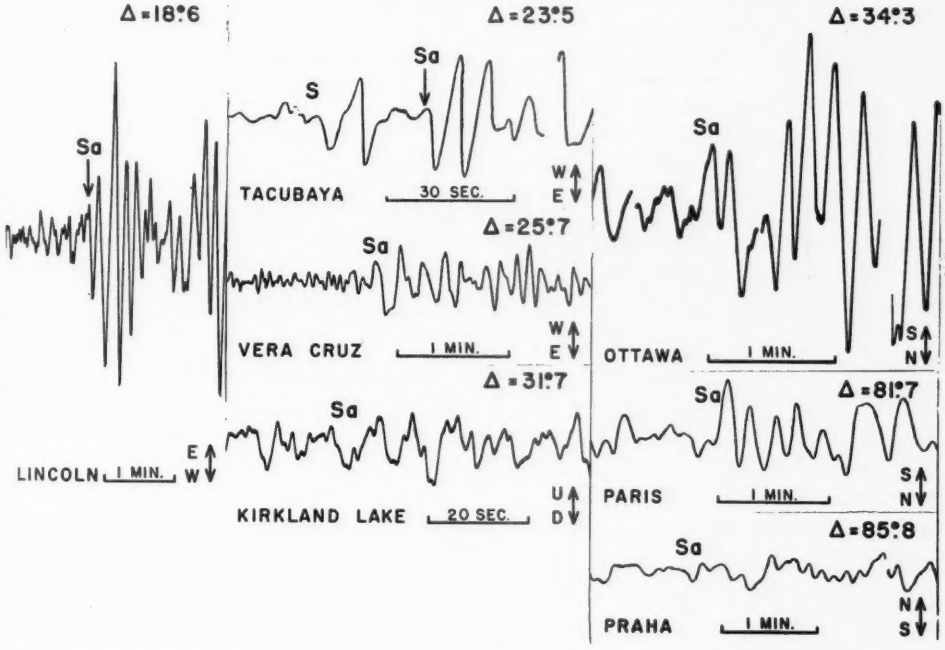


FIG. 5. Portions of selected records of the main Kern County, California, earthquake of 1952, showing *Sa*. Δ=epicentral distance in degrees; arrows indicate direction of ground motion.

*Sa* has a considerable vertical component, and this is confirmed by records of the California shock of 1952.

There is general agreement that *Pa* and *Sa* waves are found which have travelled through oceanic crustal layers. Both phases have been observed on European records of the 1952 California shock, and *Pa* was recorded (with some doubt) at Huancayo, La Paz, and Apia; *Sa* was recorded at Honolulu. There is no indication of *Pa* or *Sa* on records written in Japan or New Zealand, but this may be a result of not-well-suited instrumental constants in Japan and of large microseisms in New Zealand. Thus far, there is no clear evidence that the asthenosphere channel is missing in any of the larger units of the earth's crust.

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GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955), PP. 295–306, 4 FIGS.

# ORTHOGONAL POLYNOMIALS: THEIR USE IN ESTIMATING THE REGIONAL EFFECT*

C. H. G. OLDHAM† AND D. B. SUTHERLAND‡

## ABSTRACT

The examination of experimental data for significant trends by orthogonal polynomials is well known in statistics. The method is adapted here to the estimation of regional trends in potential field observations, and two characteristically-different gravity maps are analyzed.

The method is found to agree closely with a graphical solution in an area of fairly smooth contours, and to give a reasonable solution in an area where the graphical method would be difficult to apply. It is proposed that the orthogonal polynomials could also be adapted to evaluating total mass and to interpreting second derivative maps.

## INTRODUCTION

DeLury (1950) has tabulated the values of the Tchebycheff orthogonal polynomials for all values of $n$ up to 26. In the introduction to his book, DeLury has shown how these tables may be used to estimate the trends in experimental data. The method is based on the principle of least squares and requires that the experimental observations be known at equally spaced intervals.

At the suggestion of F. S. Grant, this process was adapted by the authors to investigate the regional trends in two overlapping sets of gravity data in southeastern Ontario.

The regional effect found by this method is a low-order polynomial surface. The resulting residuals are analogous to the random error found in any set of experimental observations, and are here assigned to near-surface effects. This system of fitting a surface by least squares differs from those previously described by Agocs (1952) and Simpson (1954) in that the calculations provide a means for limiting the choice of the order of the surface which best describes the regional trend. A unique solution should not be expected since the term "regional effect" is in itself ambiguous.

The computations require the multiplication of matrices and other laborious mathematical operations. These computations were greatly simplified by using the University of Toronto's Ferut Electronic Computor.

## THEORY

The theory is outlined below for the case of estimating the regional trends in gravity data. The method is equally applicable to other geophysical problems where trends in experimental data require estimation. A more complete discussion of the theory is given by DeLury in the introduction to his tables.

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It is assumed that the observed gravity field is composed of both regional and residual components. Thus, at any point the measured Bouguer anomaly may be written as:

$$y_i = \eta_i + \epsilon_i,$$

where

$y_i$ = the value of the Bouguer anomaly

$\eta_i$ = the component due to the typically deep-seated density variations (regional effect or trend)

$\epsilon_i$ = the residual component assumed due to relatively near surface density variations (local effects).

It is assumed that $\epsilon_i$ is a random variable with a zero mean and variance $\sigma^2$ which is the same for all the observations. Thus, the residual component is regarded as being similar to the random error found in any set of experimental data.

The variable $\eta$ may be expressed as a polynomial in the two-coordinate variables $u$ and $v$.

$$\eta = f(uv) \equiv a_{00} + a_{10}u + a_{01}v + a_{11}uv + a_{20}u^2 + \cdots + a_{qp} \cdot u^q v^p. \qquad (1)$$

This polynomial $f(u, v)$ may be rewritten in terms of the orthogonal polynomials

$$\xi_0'(u), \xi_0'(v), \xi_1'(u), \cdots, \xi_q'(u), \cdots \xi_p'(v),$$

where $\xi_r'(u)$ is the orthogonal polynomial in $u$ of degree $r$, and by definition

$$\sum \xi_r'(u) \cdot \xi_s'(u) = 0 \qquad r \neq s.$$

Then

$$\eta = b_{00}'\xi_0'(u)\xi_0'(v) + b_{10}'\xi_1'(u)\xi_0'(v) + b_{11}'\xi_1'(u)\xi_1'(v) \cdots + b_{qp}'\xi_q'(u)\xi_p'(v). \qquad (2)$$

Let $y_{ij}$ be a set of observations (gravity anomalies) on $\eta$ corresponding to $u_i, v_j$, where

$$i = 0, 1, 2, \cdots, n \qquad n > q$$

$$j = 0, 1, 2, \cdots, m \qquad m > p$$

and where

$$u_{i+1} - u_i = d_1$$

$$v_{j+1} - v_j = d_2,$$

i.e., the $(u, v)$ points are spaced uniformly over a rectangular grid.

By fitting equation (1), or equivalently (2), to the observations one could obtain an estimate of the dependence of $\eta$ on $u$ and $v$.

Adopting the principle of least squares, an estimate of equation (2) can be

obtained in the form:

$$Y = B_{00}'\xi_0'(u)\xi_0'(v) + B_{10}'\xi_1'(u)\xi_0'(v) + \cdots + B_{qp}'\xi_q'(u)\xi_p'(v), \tag{3}$$

the $B'$ coefficients being determined by the normal equations:

$$\sum_{r=0}^{q}\sum_{s=0}^{p} B_{rs}'S\{\xi_r'^2(u)\}S\{\xi_s'^2(v)\} = Sy\xi_r'(u)\xi_s'(v) = g_{rs}, \tag{4}$$

where $S$ denotes summation over all the observations. (See, for example, DeLury (1950, p. 4), and Kendall (1946, p. 147).)

The estimates of the parameters of equation (2) are therefore given by

$$B_{rs}' = \frac{g_{rs}}{S\{\xi_r'^2(u)\}\cdot S\{\xi_s'^2(v)\}}. \tag{5}$$

Using matrix notation equation (4) may be written as

$$[g] = [\xi_q']'[y][\xi_p'] \tag{6}$$

where the respective orders of the matrices are $(q, p)$, $(q, q)$, $(q, p)$, and $(p, p)$, and where $[\xi_q']'$ denotes the transform of $[\xi_q']$.

The value of each $y$ has been assumed to differ from that of the corresponding $\eta$ by an error whose mean value is zero and whose variance has the same value for all the observations. It is assumed that the errors are uncorrelated (i.e. the co-variance is zero). If, in addition, the errors are distributed normally, then the quantities

$$Z_{rs} = \frac{g_{rs}}{\sqrt{S\{\xi_r'^2(u)\}S\{\xi_s'^2(v)\}}} \tag{7}$$

are normally and independently distributed with a variance $\sigma^2$. Furthermore, the component $Z_{rs}(r, s=0, 1, 2\cdots)$ may be expressed as a linear function of the $r$th differences in the $u$-direction of the $s$th differences in the $v$-direction of the observations. This array can therefore be regarded as a two-dimensional difference table. The $Z_{rs}$ (or alternately the $Z_{rs}^2$) array therefore provides a method for determining the order of the polynomial which best describes the regional trend. The advantage of using the $Z^2$ array is that the terms attributed to error alone will be distributed as $\sigma^2\chi^2$ and may be tested for homogeneity. Just how the $Z^2$ array may be used to limit the order of the regional surface equation will be demonstrated in the next section.

## APPLICATION

Figure 1 is a map showing Bouguer anomalies of part of the Grenville Province of the pre-Cambrian shield in southeastern Ontario. This semi-regional map is a compilation of the work of various graduate students at the University of

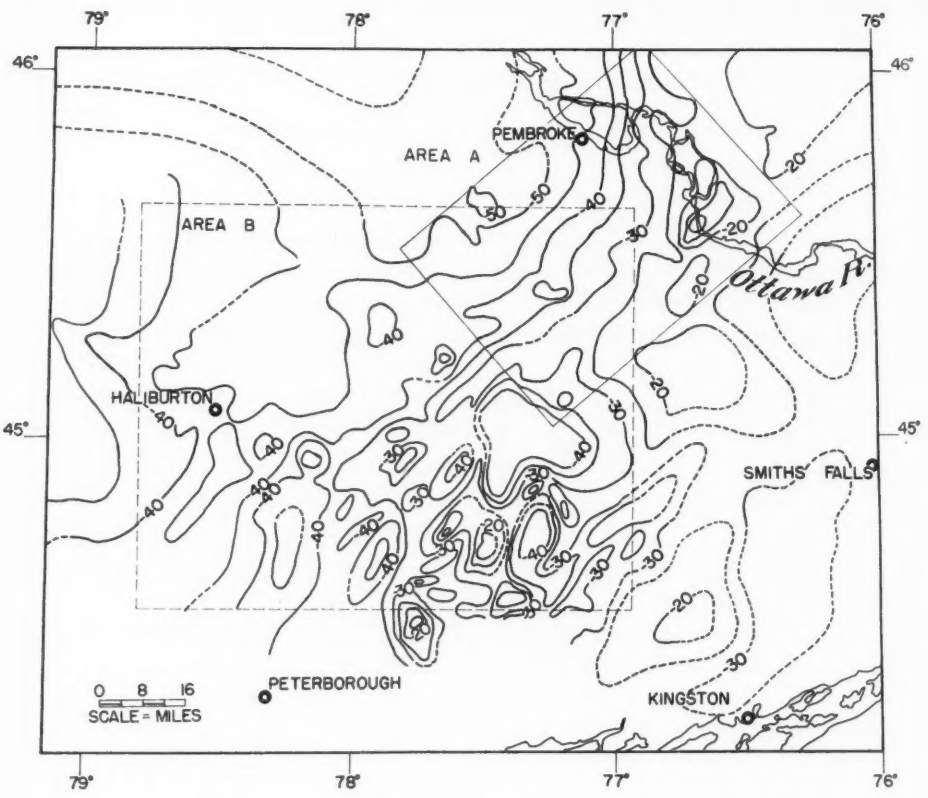


FIG. 1. Contour map of Bouguer anomalies in S-E Ontario. Areas *A* and *B* indicated by rectangles. Contour interval 5 milligals.

Toronto, and represents part of a continuing study of this complex area of highly metamorphosed basement rocks.

In order to test the method as fully as possible, two characteristically different areas were analyzed. These areas are outlined by the rectangles *A* and *B* in Figure 1. Area *A* lends itself readily to the method of smoothing contours, while this method is not so easily applied for the more complex area *B*. Since the tables calculated by DeLury are applicable only to observations taken at equal intervals, it has been necessary to interpolate the values of the Bouguer anomalies to fit them to a grid. Furthermore, DeLury has only tabulated the orthogonal polynomials for $n$ up to 26, and this limits the application of the method to an array of gravity data not greater than $26 \times 26$. Therefore, in order to analyze a sufficiently large area, a square grid with a four-mile spacing was used for each of the two areas. The sides of the rectangle were taken as coordinate axes with the origin at the northwest corner, as illustrated in Figures 2 and 3 and in Table IV.

TABLE I

ARRAY OF DATA INTERPOLATED AT NODES OF GRID FOR AREA A. VALUES ARE STATED IN TENTHS OF MILLIGALS

| $v$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $u$ | | | | | | | | | | | | | | | | |
| 0 | −507 | −520 | −510 | −514 | −511 | −530 | −520 | −500 | −475 | −477 | −463 | −426 | −410 | −360 | −330 | −290 |
| 1 | −490 | −496 | −492 | −510 | −500 | −510 | −515 | −528 | −504 | −481 | −470 | −464 | −405 | −335 | −285 | −265 |
| 2 | −445 | −480 | −498 | −500 | −504 | −510 | −510 | −525 | −500 | −451 | −447 | −440 | −365 | −310 | −257 | −240 |
| 3 | −420 | −458 | −476 | −467 | −472 | −490 | −495 | −495 | −495 | −436 | −380 | −340 | −290 | −270 | −250 | −221 |
| 4 | −402 | −420 | −440 | −460 | −448 | −425 | −425 | −425 | −417 | −390 | −375 | −305 | −277 | −230 | −288 | −222 |
| 5 | −425 | −396 | −390 | −395 | −420 | −386 | −373 | −354 | −375 | −355 | −330 | −280 | −270 | −252 | −240 | −224 |
| 6 | −375 | −390 | −368 | −370 | −330 | −360 | −338 | −332 | −320 | −326 | −304 | −274 | −242 | −220 | −250 | −210 |
| 7 | −282 | −296 | −318 | −330 | −345 | −325 | −318 | −293 | −290 | −287 | −273 | −238 | −220 | −168 | −223 | −209 |
| 8 | −318 | −290 | −295 | −300 | −295 | −280 | −288 | −275 | −235 | −278 | −215 | −100 | −152 | −137 | −225 | −209 |
| 9 | −345 | −268 | −295 | −295 | −284 | −240 | −260 | −243 | −220 | −245 | −215 | −190 | −173 | −175 | −220 | −200 |
| 10 | −398 | −300 | −320 | −280 | −245 | −230 | −228 | −226 | −197 | −195 | −183 | −228 | −219 | −195 | −220 | −200 |
| 11 | −430 | −410 | −320 | −270 | −240 | −220 | −216 | −216 | −196 | −210 | −238 | −240 | −237 | −253 | −270 | −250 |

TABLE II

$Z_{uv}^2$ ARRAY, AREA A

| $v$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $u$ | | | | | | | | | | | | | | | | |
| 0 | 21,807,900 | 585,841 | 45,854 | 758 | 6,641 | 465 | 680 | 2,962 | 778 | 1,027 | 226 | 22 | 482 | 387 | 1 | 48 |
| 1 | 1,194,170 | 22,041 | 155,050 | 141 | 158 | 750 | 89 | 1,767 | 42 | 66 | 71 | 12 | 253 | 440 | 355 | 76 |
| 2 | 34,476 | 908 | 17,706 | 13,680 | 2,115 | 33 | 410 | 3,829 | 70 | 353 | 5 | 431 | 162 | 46 | 5 | 182 |
| 3 | 57,423 | 3,135 | 665 | 2,833 | 236 | 724 | 468 | 1,345 | 80 | 2 | 233 | 266 | 2,027 | 503 | 165 | 157 |
| 4 | 324 | 296 | 6,926 | 318 | 720 | 41 | 307 | 29 | 1,768 | 846 | 103 | 23 | 262 | 5 | 233 | 85 |
| 5 | 71 | 1,550 | 651 | 73 | 25 | 815 | 4 | 573 | 524 | 86 | 4 | 102 | 53 | 26 | 50 | 45 |
| 6 | 758 | 304 | 1,596 | 6,079 | 1,126 | 0 | 2,337 | 421 | 117 | 368 | 237 | 9 | 305 | 613 | 0 | 10 |
| 7 | 130 | 6 | 775 | 8 | 499 | 47 | 48 | 1,621 | 28 | 583 | 2 | 40 | 284 | 640 | 42 | 19 |
| 8 | 1,110 | 17 | 333 | 1,688 | 232 | 4 | 387 | 129 | 1 | 62 | 79 | 246 | 281 | 90 | 23 | 0 |
| 9 | 392 | 92 | 565 | 149 | 40 | 84 | 57 | 114 | 0 | 157 | 0 | 70 | 140 | 799 | 26 | 0 |
| 10 | 124 | 1,394 | 769 | 18 | 1,326 | 210 | 1,274 | 121 | 278 | 631 | 458 | 58 | 215 | 16 | 1 | 100 |
| 11 | 9 | 103 | 458 | 2 | 8 | 114 | 984 | 128 | 134 | 422 | 2 | 182 | 513 | 3 | 190 | 375 |

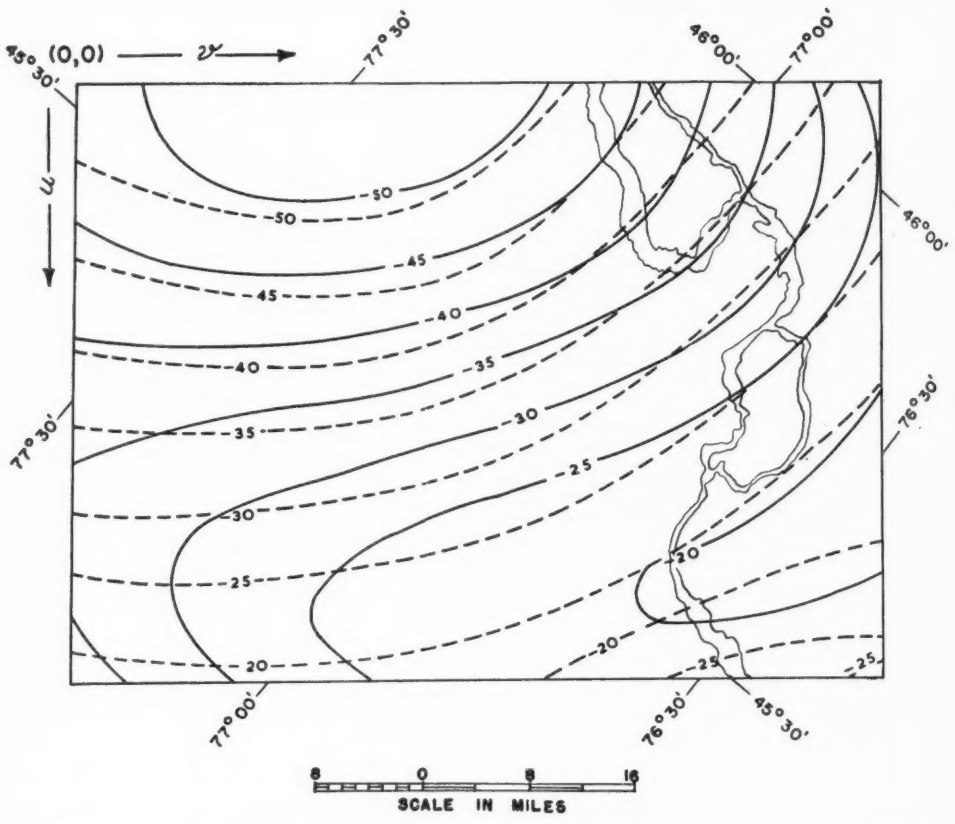


FIG. 2. Regional solutions for Area *A*. Solid lines are for orthogonal-polynomial solution, dashed lines are for graphical solution. Contour interval 5 milligals.

*Area A*

The interpolation of the contours in this area to fit the four-mile grid gave a 16 by 12 array. The values chosen at the nodes are shown in Table I.

It is necessary first to calculate the $g_{rs}$ array which, from equation (5), can be obtained by forming the triple matrix product:

$$[g] = [\xi_{12}']'[y][\xi_{16}']$$

where the prime outside the bracket denotes transposition of the matrix, $[g]$ the required array, $[y]$ the array of the data, $[\xi_{16}']$ the orthogonal polynomials for $n=16$ and $[\xi_{12}']$ the orthogonal polynomials for $n=12$.

The transposition of the $\xi_{12}'$ matrix was necessary to reveal the trend in the $u$ (i.e., 12) direction.

To obtain the $Z_{uv}^2$ array, each element in the $g$ matrix was squared and divided by the product of the corresponding sums of squares of the orthogonal poly-

nomials. The $B_{uv}'$ array was found by dividing the appropriate $g_{rs}$ by the same product of the corresponding sums of squares.

The $Z^2$ array for Area $A$ is shown in Table II. Theoretically, one would expect that the effects of the trend would be concentrated in the upper left-hand corner, and that proceeding from this corner, the effects of the trend would become smaller until at some point they would disappear altogether, leaving the remaining $Z^2$'s distributed as $\sigma^2\chi^2$.

The separation of the $Z^2$ components into two sets, one representing the regional trend and the other local effects, can usually be made by inspection.

DeLury suggests that a test proposed by Bartlett (1934) may prove helpful in cases where the decision is difficult to reach. Further, once the division has been made, the $Z^2$ components assigned to local effects may be tested for homogeneity and significance, since they are distributed as $\sigma^2\chi^2$.

The separation of the $Z^2$ array for Area $A$ was performed by inspecting each row and column and marking the first place where the magnitude of the values appeared to change abruptly. The authors' choice is indicated on Table II by the broken line through the array of numbers.

The terms above and to the left of the line are those which contain the effects of the regional trend, while the remainder determine the local anomalies. There is no statistical basis for including the $Z_{20}^2$ and $Z_{30}^2$ terms in this choice. However, it can be seen from Figure 1 that the reversal in the east corner of rectangle $A$ is part of the regional effect. In order for the surface to show this reversal in the $u$ direction it must contain a cubic term.

It might be felt that the $Z_{22}^2$ and $Z_{23}^2$ terms should also be included since they are of the same magnitude. No conclusive argument can be offered to refute this argument. They were included in a trial solution and an undesirably steep gradient was observed in the east corner; hence it was considered more reasonable to omit them.

The $B_{uv}'$ terms corresponding to the $Z_{uv}^2$ terms which were chosen to represent the trend were selected from the $B_{uv}'$ array and were substituted in equation (3) to give the estimated regional effect at the nodes of the grid. These terms are

TABLE III

PART OF THE ARRAY OF COEFFICIENTS $B_{uv}'$. NOTE CORRESPONDENCE OF TERMS WITH THOSE IN $Z^2$ ARRAY OF TABLE II. SOLID LINE INDICATES COEFFICIENTS THAT DETERMINE THE TREND.

| $v$ | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| $u$ | | | | | | |
| 0 | −337.0208 | +5.9914 | +0.79987 | −0.00792 | −0.34304 | −0.01385 |
| 1 | + 11.4229 | −0.1683 | −0.21784 | +0.00049 | +0.00077 | +0.00256 |
| 2 | −0.4235 | −0.0074 | −0.016064 | +0.00106 | +0.00061 | +0.00126 |
| 3 | −0.8350 | +0.0212 | +0.00475 | +0.00074 | +0.00312 | −0.00084 |
| 4 | −0.0503 | −0.0052 | −0.0123 | +0.00020 | +0.00000 | −0.00000 |
| 5 | −0.0167 | −0.0084 | +0.00268 | +0.00007 | −0.00006 | −0.00001 |

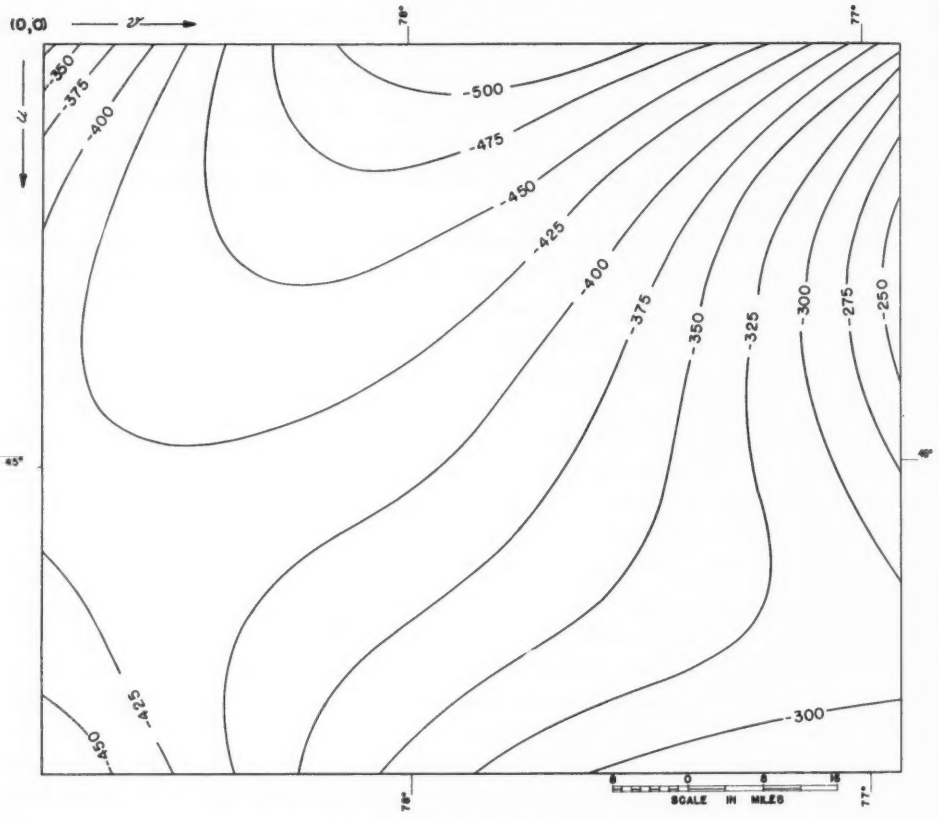


FIG. 3. Regional gravity map of Area B. Orthogonal polynomial—solution I. Contour interval $25 \times 10^{-1}$ milligals.

indicated by the broken line on the $B_{uv}'$ array in Table III.

Two methods are available for solving this equation. The surface may be expressed as a polynomial in $u$ and $v$ or as an array of numbers resulting from the multiplication of the $B'$ coefficients by the appropriate tabulated values of the orthogonal polynomials. The latter lends itself to matrix multiplication and will be illustrated in the example designated as Area $B$.

The first method was employed for Area $A$. The expressions for the orthogonal polynomials in terms of a co-ordinate variable (Kendall, 1946, page 160) were multiplied by the appropriate $\lambda$ value (Fisher and Yates, 1948) and by the corresponding coefficient taken from the $B_{uv}'$ array (Table III). The resulting regional effect in terms of $u$ and $v$ is given by:

$$\eta = 464.2 - 3.196v^2 - 32.26v - 5.862vu - 0.43568v^2u - 12.06u - 7.914u^2 - 0.55664u^3. \quad (8)$$

Equation (8) was evaluated for each node and the points contoured as shown in Figure 2. Also shown on Figure 2 is the regional surface that was obtained by smoothing the contours of Figure 1.

It can be seen that the two surfaces are quite similar. One may conclude, therefore, that this method gives a reasonable estimate of the regional effect in any area where a trend is well developed.

*Area B*

The method was also applied to the more complex area south and west of Area A which is indicated by rectangle *B* on Figure 1. The interpolation of the Bouguer values to fit the four-mile grid gave an array of numbers 24 by 20. The

TABLE IV

PART OF $Z_{uv}^2$ ARRAY, AREA B

| $v$ / $u$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 72,338,787 | 750,600 | 221,280 | 26,499 | 21,100 | 13,000 | 1,000 | 11,097 | 591 | 1,900 | 20 | 3,517 |
| 1 | 374,000 | 48,673 | 267,244 | 59,201 | 2,002 | 23,340 | 3,570 | 7,574 | 736 | 0 | 311 | 5,300 |
| 2 | 20,880 | 27,205 | 4,217 | 6,844 | 16,000 | 325 | 4,732 | 229 | 95 | 125 | 1 | 700 |
| 3 | 12,059 | 54,674 | 20,352 | 61 | 2,710 | 318 | 299 | 5,248 | 2,450 | 2,873 | 4,018 | 1,441 |
| 4 | 200 | 34 | 130 | 4,462 | 14,006 | 3,593 | 690 | 10 | 1,206 | 219 | 576 | 4,656 |
| 5 | 1,200 | 37,276 | 366 | 5,185 | 15,640 | 364 | 10,913 | 347 | 2,548 | 1,952 | 640 | 5,514 |
| 6 | 11,800 | 3,029 | 1,885 | 3,840 | 516 | 2,209 | 1,161 | 1,144 | 2,358 | 36 | 1,903 | 101 |
| 7 | 50 | 29,140 | 0 | 9,442 | 17,570 | 99 | 4,858 | 1,092 | 1,893 | 34 | 2,062 | 2,940 |
| 8 | 2,700 | 1,362 | 89 | 303 | 2,312 | 5,060 | 2,710 | 5,796 | 3,801 | 174 | 9,622 | 2,469 |
| 9 | 700 | 11,169 | 1,742 | 61 | 2,400 | 650 | 2,230 | 215 | 56 | 282 | 2 | 48 |
| 10 | 20 | 236 | 1,015 | 1,857 | 200 | 2,906 | 185 | 5,082 | 399 | 1,136 | 4,978 | 2,649 |
| 11 | 1,226 | 4,178 | 635 | 288 | 3,200 | 2,359 | 27 | 1,920 | 596 | 62 | 1,608 | 2,258 |
| 12 | 400 | 288 | 404 | 4 | 500 | 1,057 | 288 | 43 | 294 | 591 | 165 | 166 |
| 13 | 620 | 1,317 | 1,729 | 206 | 12 | 52 | 0 | 129 | 103 | 1,775 | 156 | 197 |
| 14 | 100 | 80 | 1,339 | 839 | 94 | 754 | 734 | 7 | 743 | 254 | 63 | 1,079 |
| 15 | 200 | 125 | 213 | 157 | 100 | 184 | 4 | 107 | 100 | 40 | 538 | 1,437 |
| 16 | 1,100 | 59 | 174 | 26 | 20 | 105 | 100 | 2 | 843 | 505 | 158 | 62 |
| 17 | 4 | 8 | 184 | 315 | 150 | 76 | 288 | 1,382 | 234 | 342 | 297 | 33 |
| 18 | 590 | 50 | 1 | 340 | 300 | 218 | 745 | 2,569 | 22 | 374 | 0 | 10 |
| 19 | 900 | 2 | 286 | 132 | 290 | 0 | 6 | 37 | 64 | 22 | 754 | 503 |

$Z_{uv}^2$ array for Area *B* (a part of which is reproduced as Table IV) was obtained in the same way as for Area *A*.

Two choices of the $Z^2$ components were made for Area *B*. The first choice is indicated by the solid line on the $Z_{uv}^2$ array of Table IV. The equation for $\eta$, the regional surface, was derived in a similar manner to the equation in area *A*, and gave rise to the following expression:

$$\eta = -318 - 34.2v + 1.41v^2 - 28.0u + 2.64u^2 - 0.856u^3 + 5.35uv - 0.0957uv^2 - 0.333u^2v + 0.01038u^3v.$$

This equation was evaluated for each grid intersection and these values were contoured to give the regional surface I, as shown in Figure 3.

The above procedure for obtaining the regional map is laborious and is not suggested for orders higher than 3. A more elegant method is to form the following matrix product

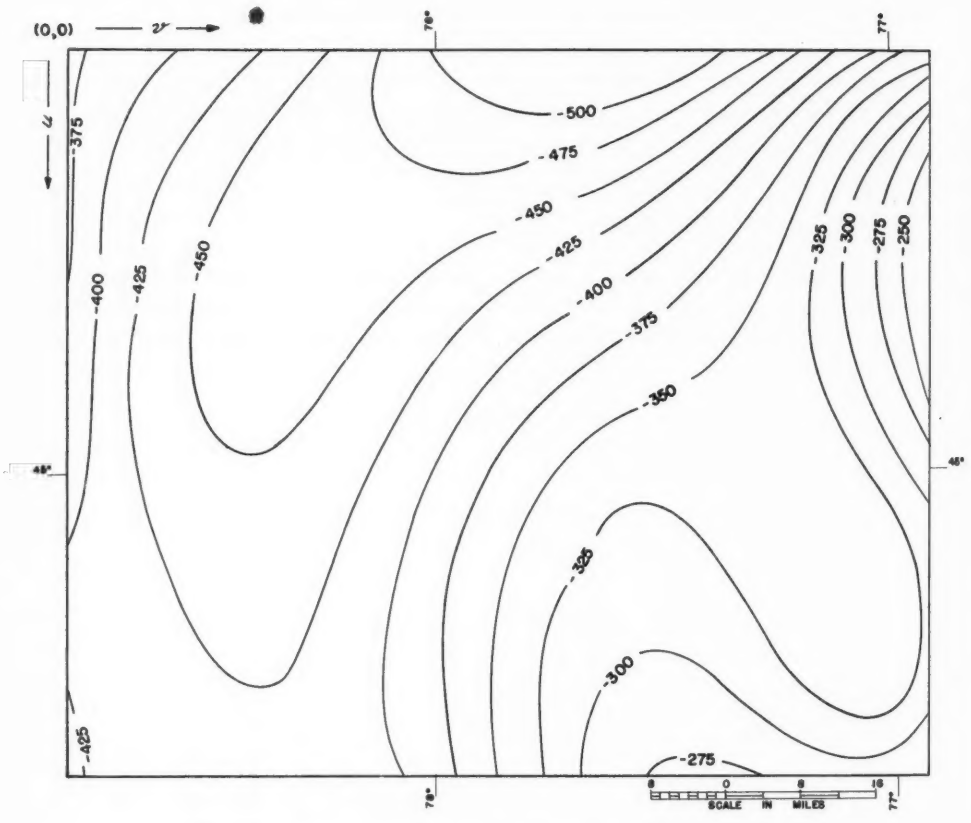


FIG. 4. Regional gravity map of Area *B*. Orthogonal polynomial—solution II. Contour interval $25 \times 10^{-1}$ milligals.

$$[\xi_{20}'][B_t'][\xi_{24}']' = [T], \tag{9}$$

where $[B_t']$ is a matrix whose non-zero elements are only the $B_{uv}'$ coefficients which are assigned to trend. The $B_{uv}'$ coefficients so assigned are those which correspond to the choice made from $Z_{uv}^2$ array. $[T]$ is an array of the values of the regional effect at the nodes, and may be contoured directly. $[\xi_{20}']$ and $[\xi_{24}']$ are the orthogonal polynomials of orders 20 and 24 respectively.

It follows that the residual map representing the local effects could be obtained directly from

$$[\xi_{20}'][B_e'][\xi_{24}']' = [L] \tag{10}$$

where $[B_e']$ is a matrix whose non-zero elements are those coefficients which are assigned to error, and $[L]$ is the array of values to be contoured.

The matrix multiplication procedure was used to obtain the regional solution II (Figure 4). The separation of the $Z_{uv}^2$ array that gives rise to this solution is

indicated on Table IV by the broken lines. This second choice was considered to be the only reasonable alternative to the first.

The effect of including these high order terms in solution II is shown clearly by the pronounced "nosing" of the $-32.5$-milligal contour in the southeast of the area. The nosing in the southeast corner coincides with two low-density granite batholiths, which for the purpose of this semi-regional survey may be classed as "local" effects. Further, the curvature of some of the other contours is too great to be attributed to typically deep-seated structures. Solution I was therefore considered to give the best representation of the regional effect.

The residual maps for these two areas were computed by subtraction, and the residual anomalies were found to be correlated closely with the known surface geology and the measured rock densities. The geological aspects of this work will be published by the authors at a later date.

## CALCULATION OF SECOND DERIVATIVES USING ORTHOGONAL POLYNOMIALS

In the foregoing, equations were obtained for the regional effect in terms of the coordinate variables $u$ and $v$. If all the coefficients ($B_{uv}$''s) were used to obtain an equation, then this equation would define a unique surface that would pass through all the original values of the observations. Then an empirical map of the second vertical derivative could be obtained from the Laplace relation

$$\frac{\partial^2 g}{\partial z^2} = -\left(\frac{\partial^2 g}{\partial u^2} + \frac{\partial^2 g}{\partial v^2}\right),$$

where $g$ is the gravity function, say $g(u, v, z)$. However, this would involve obtaining the expressions for the tabulated values of the orthogonal polynomials in terms of a co-ordinate variable (Kendall, 1946), which would be a prodigious task.

If new polynomials were defined whose values were the second derivative of the generating functions of the orthogonal polynomials tabulated by DeLury, then the process could be carried out by matrix multiplication. This would amount to computing a new set of tables. However, this may not be necessary. A scheme of operating on the $B_{uv}'$ coefficients directly, using the already tabulated values, is at present under study.

Since no practical applications have been tried at this time, the process just proposed is put forward as a hypothesis rather than as a new method. It is believed that since some smoothing could be introduced on the basis of the $Z_{uv}^2$ array, it might be possible to eliminate some of the error of the observations which often produce marked effects in second derivative maps.

## CALCULATION OF TOTAL MASS

DeLury's principal purpose in tabulating the orthogonal polynomials was to supply the arithmetical basis for a numerical integration. The advantage of this procedure over those used for ordinary numerical integration is that the error

may be eliminated from the data before the integral is evaluated. Also, the probable error for the integrated value may be obtained. This process seems particularly well suited for the estimation of the total mass causing a gravity anomaly as described by Hammer (1945).

## CONCLUSIONS

On the basis of the two examples reported, it appears that a least squares method employing orthogonal polynomials may be successfully used to estimate the regional trends in gravity data. The authors believe that the removal of the regional effect is essentially a geological problem, but in complex areas the orthogonal polynomial procedure provides some physical basis for the separation of the gravity field into regional and residual components.

This method has an advantage over usual averaging methods, since the calculations may be carried out by high-speed electronic computors. It is thought to be an improvement over previous least squares methods in that a means is provided for choosing the order of the equation that best represents the trend.

The value of the orthogonal polynomials in other fields of geophysical interpretation, such as the determination of second derivatives remains to be tested.

## ACKNOWLEDGMENTS

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GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955), PP. 307–317, 4 FIGS.

# THE SUDBURY AEROMAGNETIC MAP AS A TEST OF INTERPRETATION METHODS*

ISIDORE ZIETZ† AND ROLAND G. HENDERSON†

## ABSTRACT

The method of interpretation of aeromagnetic maps described by Vacquier, Steenland, Henderson, and Zietz (1951) is applied to several anomalies on the aeromagnetic map of part of Sudbury, Ontario. The resulting average computed depths deviate from the known depths by less than 10 percent. The aeromagnetic map is described and compared with the known surface geology.

## INTRODUCTION

The interpretation of magnetic maps may seem at the outset to be an arduous task since it is, at least theoretically, possible for an infinite number of magnetic mass distributions to produce a given anomaly. Nevertheless, through the selection of simplifying yet reasonable assumptions it becomes possible to make an estimate of the depth to magnetic sources.

It is assumed that anomalies large in areal extent and amplitude are usually due to lithologic contrasts in the basement complex rather than to the relief of the basement surface. This assumption is based on theoretical considerations, since sharp topographic rises in the basement rock will yield anomalies of relatively small amplitude. It is assumed further that the basement rocks are either magnetized by induction in the earth's magnetic field or have a remanent magnetization in the direction of the field and that this magnetization is constant with depth. In addition, the basement is assumed to be broken up into regions having vertical sides, plane horizontal surfaces with rectangular cross-sections, infinite depth extent, and internal magnetic homogeneity. These are assumptions of mathematical convenience but they are not entirely without justification.

Large bodies in the basement complex may not be petrologically homogeneous; nevertheless, a reasonable approximation can be made for the average magnetization of the entire mass. Although some rocks have a large remanent magnetization of random orientation in comparison to their induced magnetization, there is no reason to suspect that this occurs with any frequency. Where the random remanent magnetization is large, the method is not applicable.

With these fundamental assumptions, computations were made of the magnetic field for rectangular prismatic models with various cross-sections and orientations and for different inclinations of the earth's field. The field was contoured on a map with a horizontal scale expressed in terms of the depth to the top of the buried model. As an aid to interpretation, second vertical derivative maps

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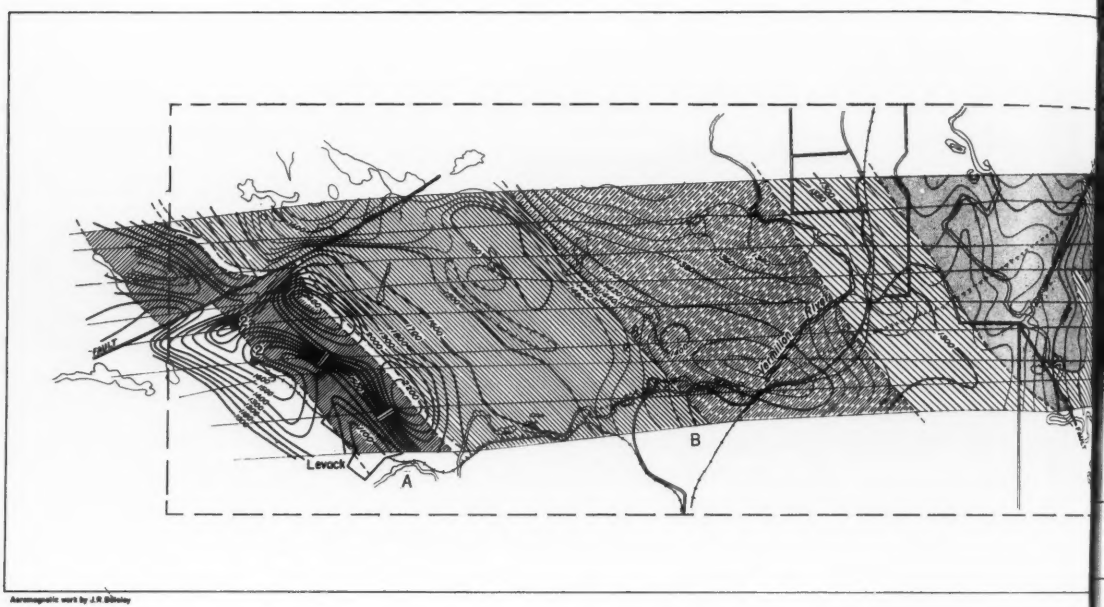
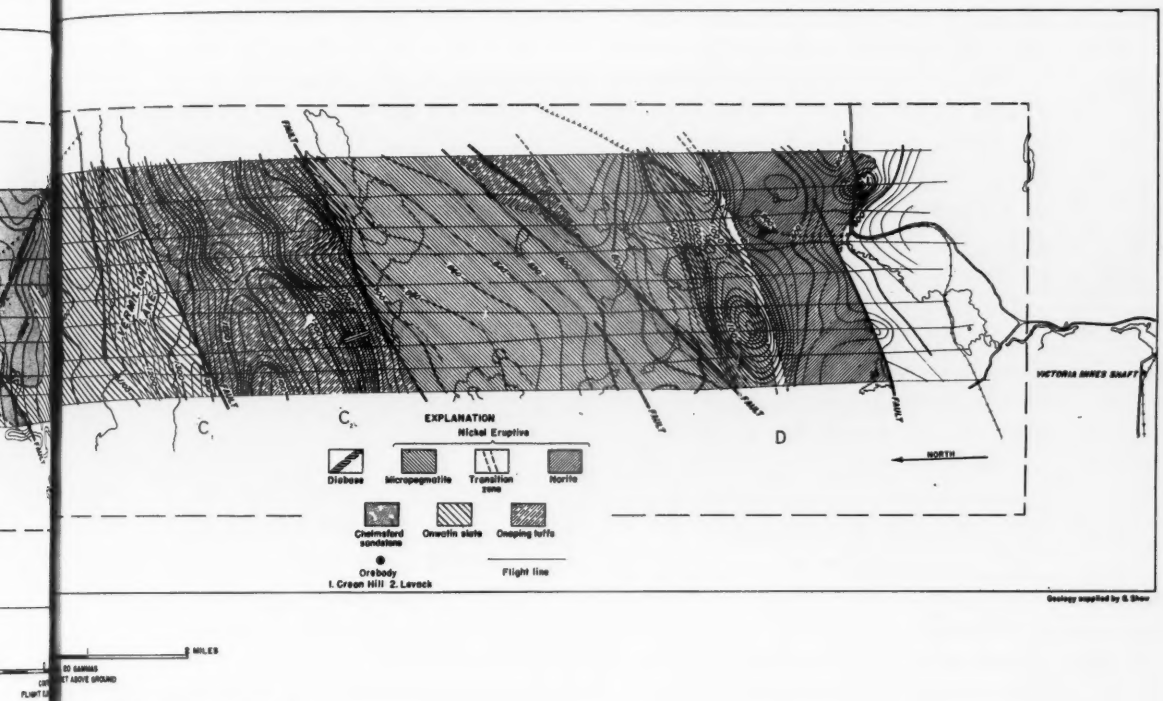



FIG. 1. General geologic and aeromag

(Henderson and Zietz, 1949) of the model fields were computed.

The depth determination procedure consists of computing a second derivative map of the observed field and comparing certain diagnostic features of the anomaly for both the observed and second derivative maps with similar features of the corresponding model. When the magnetic fields are studied, the horizontal extent of the steepest slopes are compared. When analyzing the derivative anomalies one compares the horizontal distance between maximum, minimum, and zero curvature contours.

For the method to be effective it is evident that few of the observed anomalies may be selected for interpretation. The anomalies should be magnetically "clean," i.e., the magnetic contribution from neighboring anomalies should be negligible or separable. Only those observed anomalies which have large amplitudes, cover large areas, and, in general, resemble the theoretical fields are usable. The computed depths may be considered as maximum depths in the sense that an anomaly produced by a prism with sides sloping outward will yield larger depths than the anomaly produced by the same prism with vertical sides. To satisfy this assumption of verticality, the steepest gradients of the horizontal field profiles are generally selected. In estimating the depth to a magnetic source, it is statistically advisable to make numerous measurements on any one anomaly




p of Sudbury area, Canada.

using both the field and the derivative maps, and then to use the arithmetic mean.

As shown in a memoir by Vacquier et al. (1951), the method has been tested in several areas and the results indicate that it has promise. The aeromagnetic map of the Sudbury area of Canada affords perhaps one of the better tests of the method since the geology is well known and the pre-Cambrian rocks are exposed at the surface. Using the aeromagnetic data the altitude of the airplane may be computed and compared with the known flight elevation of approximately 950 feet.

## GENERAL GEOLOGY

An excellent bibliography on the geology of the Sudbury area was prepared by Cooke (1946). A syncline of Animikie sedimentary rocks including conglomerate, tuff, and slates rests upon a basement of Keewatin greenstone and Sudbury quartzite. A laccolithic intrusion of norite-micropegmatite occurs between the basement complex and the sedimentary rocks, forming an oval ring surrounding the latter. In general its contact at the base dips 30° to 60° inward so that the structure is like the bowl of a huge spoon 37 miles long, 17 miles wide, and $1\frac{1}{2}$ miles deep. The norite-micropegmatite mass grades from a norite at the outer

edge to a micropegmatite granite at the inner edge. A definite narrow transition zone between the norite and the micropegmatite has been established by chemical and mineralogical studies of the gradational region. At the Crean Hill mine (see Figure 1) the contact between the norite and the greenstone is essentially vertical. At the Levack mine the norite dips 45° to the south at the contact with the adjacent granite gneiss. There is little information available concerning the dip of the contact between the overlying Animikie formation and the micropegmatite.

## AEROMAGNETIC MAP

At the request of the Canadian government, the U. S. Geological Survey demonstrated the use of its airborne magnetometer equipment in the fall of 1946 by an aeromagnetic survey over part of the Sudbury basin. The field work and compilation were under the direction of James R. Balsley of the U. S. Geological Survey, and the geologic information was supplied by George Shaw of the Geological Survey of Canada. The instrument used was the AN/ASQ-3A flux-gate-type total-field magnetometer. The area surveyed (see Figure 1) is a north-south strip across the western portion of the basin bounded approximately by the Levack mine at the north and Crean Hill mine at the south. The flights were made approximately 950 feet above the ground at quarter-mile spacing, running north-south; approximately transverse to the strike of the rocks.

The aeromagnetic map (Figure 1) shows many known features of the surface geology. In general, the trend of the magnetic contours follows the grain of the geologic formations. There is good correlation between the larger magnetic features and the magnetic character of known surface rocks. Both mines, No. 2 at Levack to the north and No. 1 at Crean Hill to the south, are located at magnetic highs. Production at the Levack mine is still continuing. Well-defined anomalies of large amplitude appear near the transition zone in both the north and the south regions on the map.

Collins (1934) conducted an exhaustive chemical and mineralogic investigation of the transition zone and showed that just beneath this zone at the top of the norite there is a large concentration of titaniferous magnetite. The analyses of specimens at points along profiles transverse to the transition zone indicate that this concentration is considerably greater at Levack than at Crean Hill. This difference is reflected in the magnetic map by the correspondingly larger anomalies in the north. The anomaly to the north is displaced toward the norite, which confirms Collins' analysis. However, at the south the displacement is toward the micropegmatite. This displacement may be explained in part by the fact that in the southern region the rocks dip to the north at shallow angles, causing displacements of the peaks toward the north.

The exposed norite to the north produces anomalies of much larger amplitude than those found to the south. The probable cause is a greater concentration of magnetic constituents in the norite at the north end. This interpretation is sup-

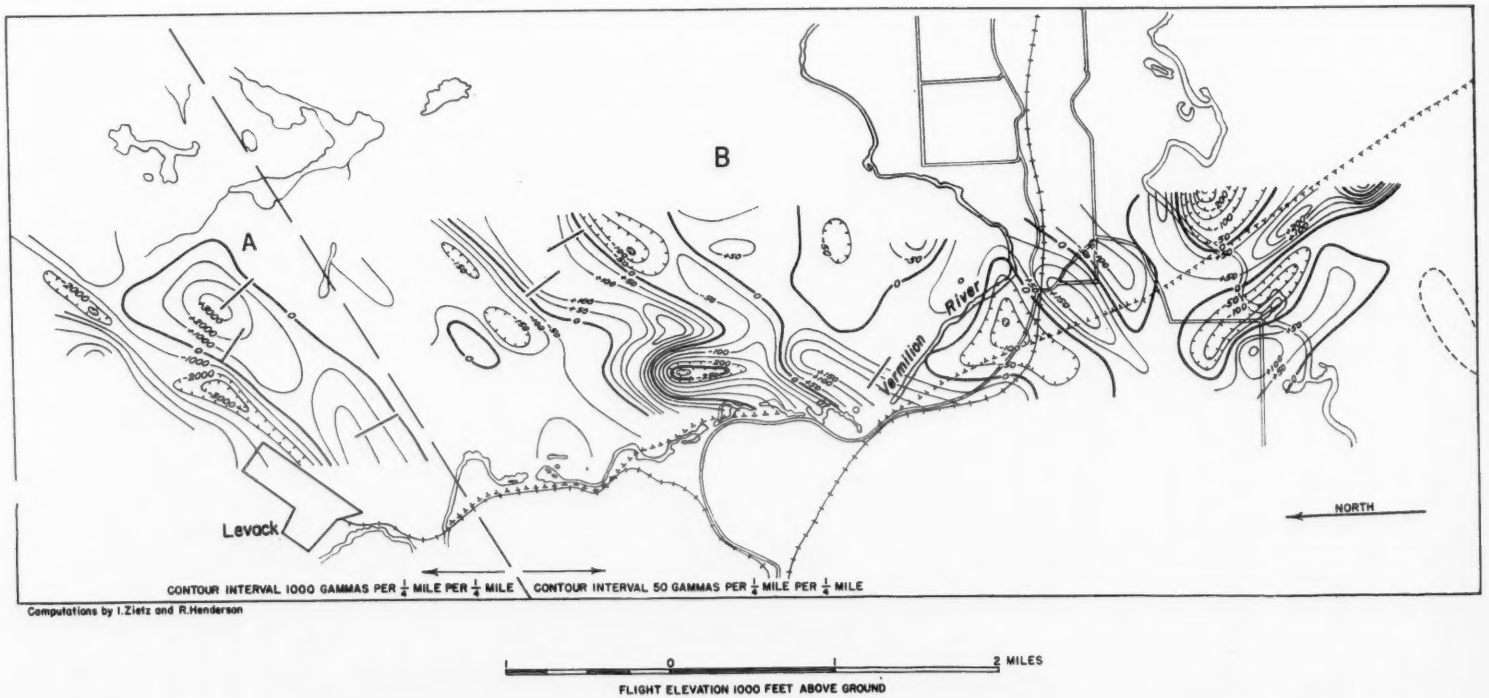



FIG. 2a. Second vertical derivative map of northern half of part of Sudbury area, Canada.

FIG. 2b. Second vertical derivative map of southern half of part of Sudbury area, Canada.

ported by the existence at the north of a larger concentration of titaniferous magnetite at the top of the norite and of magnetite in the ore itself. Anomalies having smaller amplitudes and gentler slopes occur over the Onaping tuff and the Onwatin slate, which are presumably less magnetic than the more mafic norite. The micropegmatite, which is the felsic part of the nickel-bearing eruptive rock, produces anomalies of even smaller amplitude.

The diabase dike in the Chelmsford sandstone as well as the faulting at the transition zone to the north can be closely correlated with the trend of the magnetic contours. There are also many smaller magnetic features that probably reflect inhomogeneities in the country rock.

## SECOND DERIVATIVE MAP

Second vertical derivative maps (see Figures 2a and 2b) are useful not only in determining depths to basement rock but also in bringing into greater prominence the geologic features that have only slight expression in the magnetic field. They also help delineate those geologic formations which are magnetic. For large anomalies in particular this delineation is accomplished by the zero contour. The horizontal dimensions of the theoretical model can thus be obtained by considering the dimensions of the zero curvature contour on the observed map. In determining depth, it is significant that for broad anomalies (at least two depth units wide) many of the measurements on the theoretical second derivative anomalies are independent of the horizontal dimensions of the prism. For this reason it is preferable to select broad anomalies for depth calculations. The residual map using the same grid system may be substituted for the second derivative map since it can be shown that the maximum, minimum, and zero curvature contours appear at exactly the same respective positions on both maps.

## DEPTH COMPUTATIONS

Attention is first directed to region A, where well-defined anomalies occur near the transition zone. Here the norite sheet dips at an angle of 45° at the northern contact. For the entire Sudbury area the magnetic inclination is assumed to be 75°. The model which most closely approximates the horizontal dimensions of the perturbing mass distribution as indicated by the zero curvature contour is 0.707 (4×8) striking N 45°E. This model represents a body whose dimensions are 2.8×5.7 expressed in terms of a unit depth of burial. The theoretical total intensity and second vertical derivative maps of this model are presented in Figures 3 and 4 respectively. It should be noted that for models striking N 45°E the grid length was changed to 0.707 of a depth unit for convenient calculation. To the north of the anomaly, field profiles yield depths of 850 feet. The derivative maps give depths of 950 feet at the north edge and 1,180 feet at the south edge. This is an average of 960 feet, in excellent agreement with the known elevation of 950 feet. The airplane was actually flown about 1,000 feet above the ground, but a correction of 50 feet must be applied since the magnetometer is suspended ap-

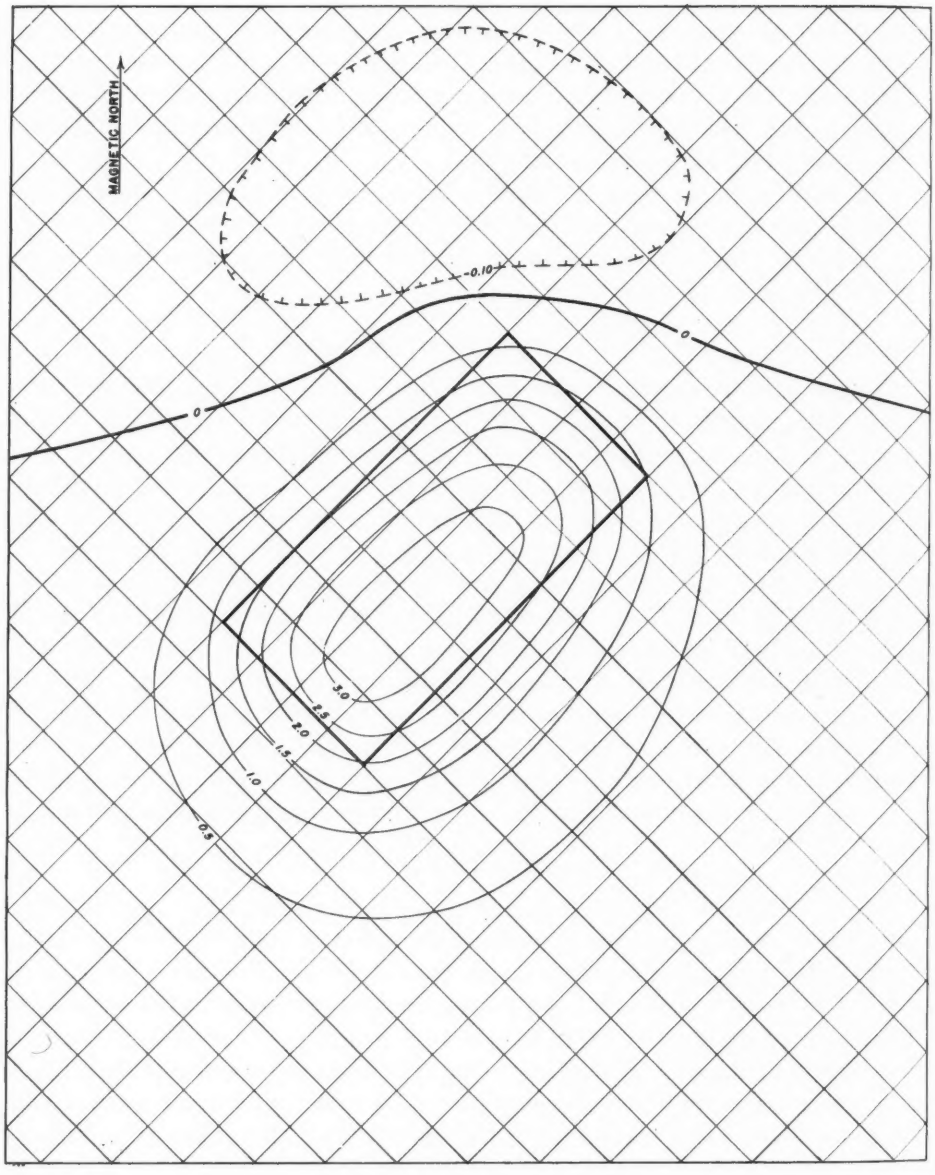
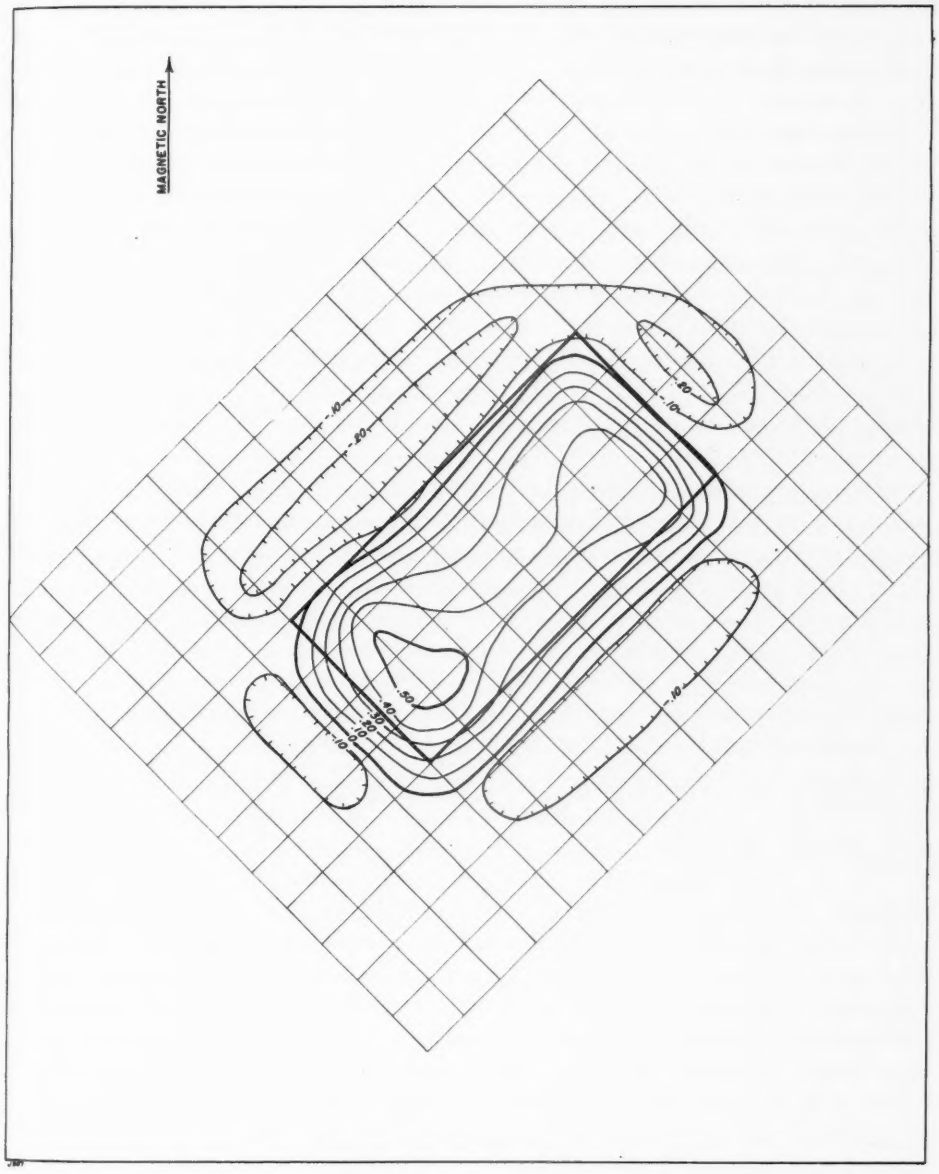



FIG. 3. Total intensity map $\Delta T/I$ (c.g.s.) for a typical model anomaly.




Curvature $\frac{\partial^2(\Delta T)}{\partial Z^2}/4I$ Inclination 75°

Grid Interval = 0.7 Depth of Burial

Strike = N. 45° E. (Magnetic)

FIG. 4. Curvature map $\partial^2(\Delta T)/\partial Z^2/4I$ for a typical model anomaly.

proximately 50 feet below the airplane. It is significant that the computed depths compare so favorably with the known depth since the assumption of vertical sides in this case is not very tenable. Actually, the individual estimates may be in error by as much as 20 percent.

In the southern region of the map, area D, another well-defined anomaly occurs at the transition zone. Here the contact between the norite and the greenstone is known to be nearly vertical. There is no information available regarding the dip of the contact between the micropegmatite and the overlying sediments, although it is presumably to the north. The zero curvature suggests the use of a model with horizontal dimensions 2.5×6. To obtain the proper proportionality factors a linear interpolation was made between the factors for the 2×6 and the 4×6 models. A measurement to the north of the total field anomaly yields a depth of 1,100 feet. The derivative map yields depths of 1,050 feet at the northern edge and 1,100 feet to the south. The three determinations result in a mean of 1,085 feet.

The micropegmatite in general gives few usable anomalies. In fact this granitic rock produces a rather broad low of small amplitude at the fault zone to the north of area D. There are also in area B two anomalies to the north and south respectively of the contact between the micropegmatite and the volcanic tuffs. The one to the north gives usable zero contours in the second derivative map but not a well-defined high. Nevertheless measurements were made that give depths of 1,050 feet. No model slope measurements were attempted because of low gradients. The only applicable measurement for the anomaly to the south of the contact is that on the south side of the anomaly on the derivative map. This gives a depth of 1,070 feet. Although both anomalies yield depths that are in accord with the known elevation, depth predictions using anomalies of this kind should be made with caution.

The anomalies located over the Onaping tuff in area C are amenable to model analysis. The zero curvature of the derivative map indicates that a 0.707 (4×8) body striking N 45°E should be selected for analysis (Figure 4). On the derivative map, a depth of 930 feet is predicted from the measurement at the south edge of anomaly $C_1$ and a depth of 785 feet from that at the north edge. The analysis of the field profile suggests a depth of 1,120 feet. These figures give a mean of 945 feet. Using the derivative map a measurement at the north edge of anomaly $C_2$ yields a depth of 860 feet and at the south edge a depth of 900 feet. The steepest slope of the magnetic profile gives a depth of 1,120 feet. The three estimated values average 960 feet.

## CONCLUSIONS

In this area, the average computed depths deviate from the known values by less than 10 percent, although individual estimates are in error by as much as 20 percent. Specifically, the interpretations of the magnetic anomalies in areas A, *B*, $C_1$, $C_2$, and *D* yield, respectively, depths of 960, 1,060, 945, 960, and 1,085 feet,

or an over-all average of 1,005 feet, which compares very favorably with the known depth of 950 feet. The interpretation also suggests that the existence of vertical sides does not impose too stringent a condition on the method, although much theoretical work remains to be done in this regard.

One of the more important objectives in this method of model analysis is to increase the objectivity of aeromagnetic interpretation. However, the simplifying assumptions mentioned previously are seldom met in practice, and as a result, some subjectivity on the interpreter's part is necessarily involved. Much of this subjectivity lies in the requirement that the interpreter select an observed anomaly that resembles the theoretical field distribution of one of the assumed models. The proper horizontal measurements must then be made on the observed anomaly for comparison with the corresponding measurements on the theoretical maps. This requires considerable judgment. Furthermore, it is important that accurate aeromagnetic maps be available since any error in the field is greatly exaggerated by the second derivative process.

The interpretive method used for the Sudbury data serves as a rapid and effective means for calculating depths. However, the real test of its accuracy lies in its application to areas where drill hole information to the basement is available It is hoped that in the future such applications will be made by those engaged in aeromagnetic interpretation.

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GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955), PP. 318–334, 8 FIGS.

# A NEW ELECTROMAGNETIC FIELD TECHNIQUE*

J. F. ENSLIN†

## ABSTRACT

A technique has been developed for accurate location of narrow vertical or inclined structures such as joints, fault planes, mineralized fissures, and weathered dykes.

An alternating current of audio-frequency is introduced conductively into the ground at a center-point. Relative or absolute measurements of the tangential component of the resultant horizontal electromagnetic field are made at stations on concentric circles around the center-point. Curves of the amplitudes, in decibels, are plotted as ordinates against the station positions. These are called the $H_T$-curves. The locations of peaks occurring vertically above current concentrations in narrow conducting zones are plotted on a map of the area and corresponding peaks are easily joined up to delineate such structures.

Phase measurements have proved to be of minor importance for the location of geologic structures.

## INTRODUCTION

A problem that often confronts the geophysicist is the accurate location of faults, crush-zones, and similar linear structures under a cover of overburden or decomposed rock. It may be encountered either in prospecting for economic mineral deposits or in the selection of borehole sites for water. From a geophysical point of view, the electromagnetic method is an ideal one for the delineation of such linear structures.

The successful application of the method depends on the resistivity contrast between the material filling the fault or the decomposed dyke rock (whose resistivity may vary between 1,000 and 30,000 ohm-cm) and the country rock (with resistivity ranging between 20,000 and 100,000 ohm-cm for sandstones, broken igneous rock, or lava-flows and extending to more than $10^6$ ohm-cm for solid igneous rocks). In addition, these structures are covered by an overburden or by decomposed rock which may have resistivities of the same order as that of the material filling the structures to be located. If the fault zone has the same resistivity as the country rock, the structures cannot be traced by the electromagnetic method.

## HISTORICAL

When the Geological Survey of South Africa decided to investigate the practical application of the electromagnetic method, Dr. R. Guelke, then Acting Professor of Electrical Engineering at the University of Cape Town, designed and constructed a field instrument for the purpose.

The instrument, already described in detail by Guelke (1945), was constructed

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for field observations according to techniques employed by Sundberg (1931), Hedstrom (1937), and others. The earth is energized by an alternating current of audio-frequency, either conductively by passing a current through a long cable earthed at both ends, or inductively by a current flowing in a large rectangular insulated loop laid out on the surface of the ground. Phase differences and amplitude ratios or other parameters of the resultant electromagnetic field are measured at various points on the ground by comparing the induced e.m.f.'s in two identical coils connected to an a-c bridge circuit.

Power is supplied by a one-kilowatt, 220-volt, 50-cycle petrol driven generator to the amplifier, excited by a tuning-fork-controlled valve oscillator, which is capable of supplying 340 watts at a frequency of 512 cps to the cable.

During the course of the experimental surveys it was found that practically no anomalies were observed across known fault zones when the current was passed through the insulated loop, whereas very prominent anomalies were obtained when the cable was earthed.

A horizontal insulated loop provides no coupling with a vertical conducting zone situated immediately below and parallel to its lines of symmetry. However, if the conducting zone lies outside, or asymmetrically below, the loop, a coupling is obtained which is often comparable with that obtained for vertical loops.

Typical curves of the vertical electromagnetic field measured along a traverse across the Dowe-Tokwe fault, a major structure in the Messina copper area, are given in Figure 1. Both insulated loops and earthed cables were used. The observed horizontal field for the insulated loop is practically identical with the theoretical primary field for the current in the loop, whereas the observed field for the earthed current differs appreciably from that for the primary current in a U-shaped loop. By correcting for the superimposed primary field, it is possible to determine the approximate position of the fault.

Where observations were made across very good conductors, such as water pipes, anomalies were observed both for the insulated and earthed cables, the amplitude for the former at one location being approximately 1/10th that of the latter.

It was, therefore, obvious that the inductive method offered very little chance of detecting narrow zones of medium conductivity, and further investigation was restricted to the electromagnetic method using an earthed primary current.

Various layouts of the earthed cable (e.g., straight cable and U-shaped cable earthed at different points relative to known structures) were used for the traverse lines. Observations of horizontal and vertical field intensities and phase angles and the angles of dip and strike of the total field were made and the observed data were interpreted by theoretical and graphical methods.

Although large anomalies were observed, the interpretations could seldom be made with the accuracy required, due to one or more of the following factors:

(1) The secondary field caused by the structure to be located was superimposed on the primary field which, very often, was not only much larger than

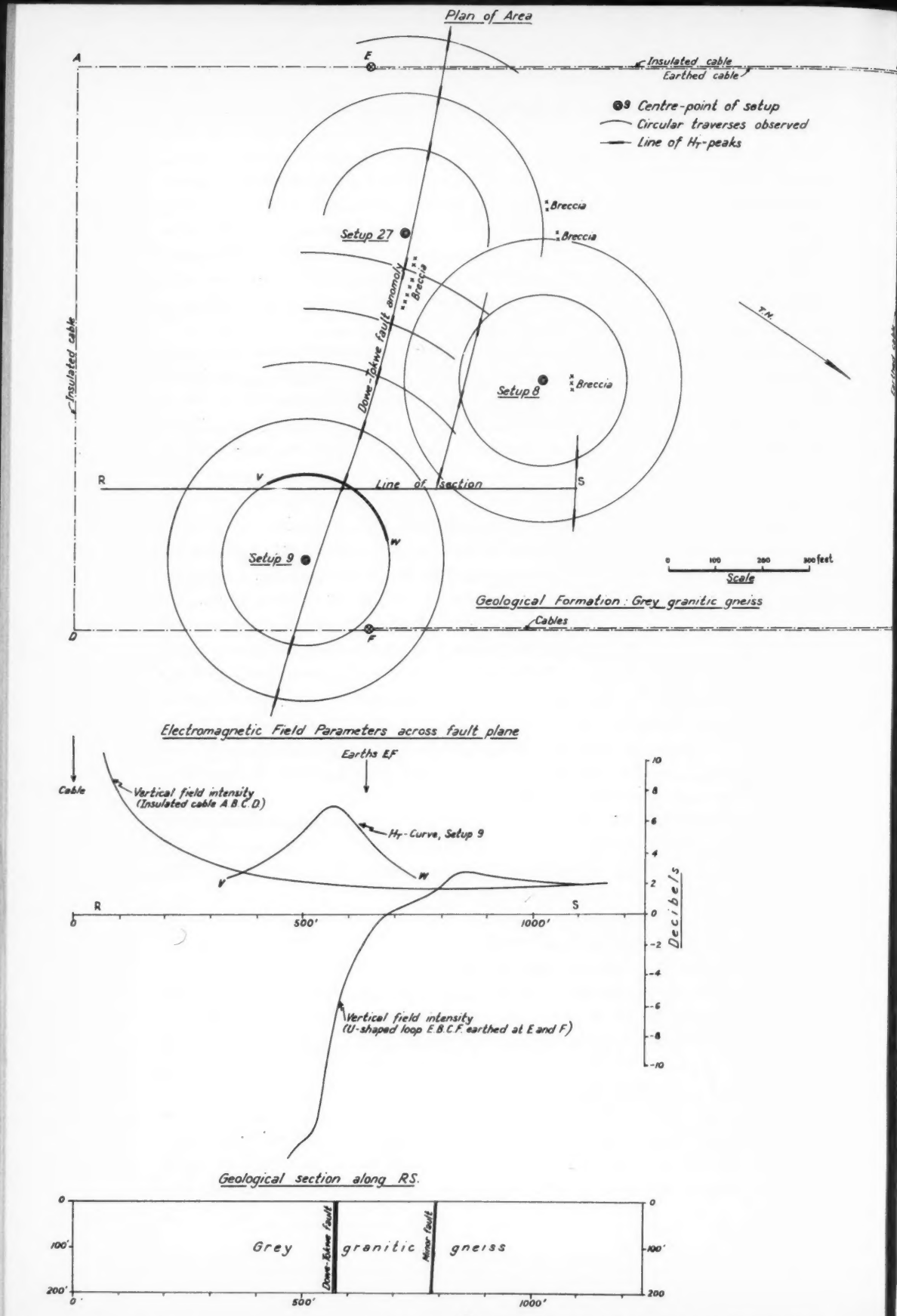



FIG. 1. Conventional electromagnetic survey of Dowe-Tokwe fault on Kilrush 812, Zoutpansberg district, Northern Transvaal.

the secondary, but was also variable depending on the position of the traverse relative to the cable.

(2) The anomaly of one structure was distorted by that due to another adjacent structure; it was generally not possible to correct for this distortion since the configuration of the second structure was not known. The interpretation thus became vague or ambiguous. This difficulty was experienced mainly with the vertical field anomalies.

(3) Apparent anomalies were observed along traverse lines crossing the normal field set up by the flow of current between the two earthed electrodes.

The ideal parameter we would like to observe in electromagnetic exploration is one which has no superimposed component of the primary field, which is constant over the traverse when the earth is homogeneous, and which has a high resolving power with respect to superimposed anomalies from nearby structures.

The field technique to be described is designed for observing a field parameter having these characteristics.

## THEORETICAL

It has been proved theoretically (Jakosky, 1950, p. 583–585) and confirmed by field observations that under certain conditions the electromagnetic field at a point $P$ on the surface of a homogeneous non-magnetic earth, due to a point source of current at a center-point O, has only a horizontal component and that the total intensity vector is tangential to a circle with center at O. The value of this field, called the $H_T$-field, is given by the following equation:

$$H_T \text{ (in gauss)} = \frac{I}{10r}, \quad \text{if}$$

$I$ is expressed in amperes and $r$ in centimeters; it is thus a constant on any circle around the center-point. This electromagnetic field is identical to the field caused by a current $I$ flowing in a vertical conductor from O to an infinite depth.

If the earth near the center-point O is not homogeneous, the current will concentrate along the conducting zones and the tangential component of the horizontal field ($H_T$-field) will not be constant on each concentric circle but will have peaks vertically above current concentrations.

This theoretical relationship offers a possible field technique for which most of the limitations of the other techniques are eliminated.

## PROPOSED FIELD TECHNIQUE

A series of suitable center-points is selected to cover the area to be surveyed for fault-zones or other narrow linear structures. At each of these centers an electrode is earthed and well watered to reduce the contact resistance to less than 500 ohms. In dry sandy soil it may be necessary to drive additional stake electrodes into the ground within a few yards of the center, add salt to the water,

and connect these electrodes in parallel with the one at the center.

Stations for routine observations are laid out on two concentric circles around each center-point, with radii of 60 and 100 yards, and further stations are laid out on arcs with radii of 140, 180, 220, etc. yards if required for tracing anomalies. There are generally 28 equally spaced stations along each circle. Stations on the respective circles are located along radial lines from the center.

The stations are all accurately plotted on a plan of the area on a scale of 1:2,000 or 1:2,500. One set of co-radial stations is marked distinctively in the field and numbered 0 on the plan and the other sets of stations can be indicated by the numbers 1, 2, 3, · · · 27 (Fig. 2).

During operations, these center-points, called set-ups, are normally spaced 220 to 250 yards apart along a line making an angle of 45° to 60° with the strike of the formation or the probable strike of the feature to be located. The power supply and transmitter are brought close to the center of the first set-up by truck. One side of the transmitter is connected to a cable laid out along the line of centers. The other side is grounded at a point about 300 yards away in a direction opposite to that along which the cable runs. The cable can be connected to each of the set-ups in turn for taking observations. The primary current varies between 0.3 and 1.5 amp for different set-ups.

Observations are generally taken simultaneously with two pick-ups, one on each circle. The coils are connected to the pick-ups and are held in the planes formed by the vertical and the respective radii.

An e.m.f. proportional to the horizontal field tangential to the circle (the $H_T$-field) is thus induced in each coil and the phase difference and amplitude ratio of the fields at the two stations are obtained by balancing for minimum current on the ammeter, using both the phase and amplitude dials. The readings are noted and the coils are moved forward one position such that the No. 2 coil occupies the station previously occupied by the No. 1 coil, and readings are taken again.

Readings are not taken on that part of the circle nearer than 30 yards from the cable carrying the primary current. If readings are taken closer to the cable, errors may be introduced by the strong primary electromagnetic field, some component of which will be picked up if the coils are not held truly vertical or if there is a difference in elevation between the cable and the coil.

On completion of the observations on the arcs of the first set-up the cable is connected to the center-point of the second set-up and the same observations are taken. The operation is repeated for the other set-ups. The truck with the power plant and transmitter is then moved to the last set-up and the transmitter is grounded about 300 yards farther on and observations are taken with the other side of the transmitter connected to each of the set-ups in turn. For the second series of readings at each set-up, the cable carrying the primary current now lies on the opposite side of the center-point from that which it occupied for the first series of readings. It is thus possible to complete the observations on the circles by

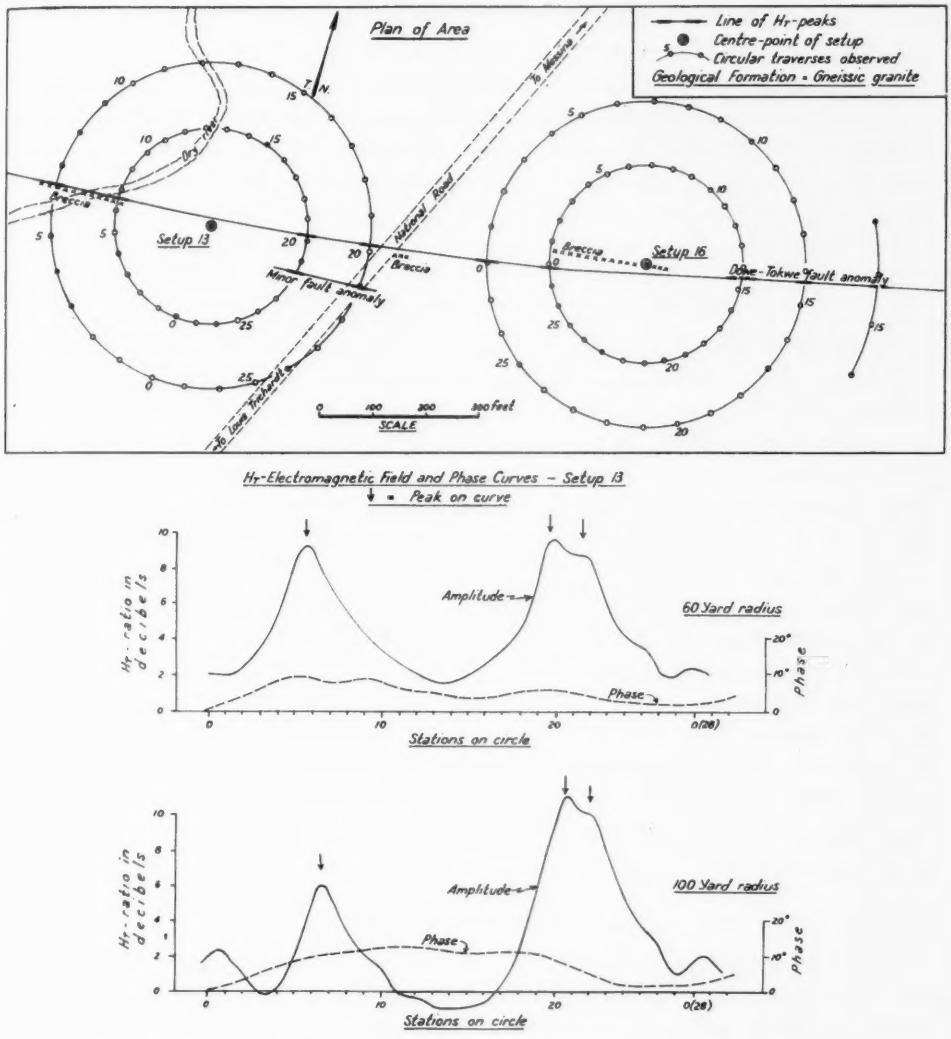



FIG. 2. Electromagnetic ($H_T$-field) survey of the Dowe-Tokwe fault, south of Messina, Northern Transvaal.

taking readings on the arcs that could not be covered originally, including an overlap of a few stations.

The amplitude ratios and the phase angles are then calculated for all stations relative to the base station, O, for each circle and plotted as ordinates against the station numbers as abscissa. The peaks of the field intensity ($H_T$-max) are very prominent and their positions can be plotted accurately on the base map. Corresponding peaks are joined on the map to show the positions of the conducting structures. These structures can be detailed by laying out stations on arcs

which cover only the extensions of the anomalies. Strong anomalies have been traced a distance of 500 yards from the center-point.

A typical lay-out of stations on set-ups 13 and 16 over the Dowe-Tokwe fault, and a plot of the amplitude ratio and phase curves for set-up 13, are given in Figure 2. It is clear that the peaks on the $H_T$-curves are very sharp and could be plotted with sufficient accuracy for the delineation of the fault plane. The phase curve, on the other hand, does not show the position of the fault well and is of minor importance. This was found to be the case for all similar structures.

## THE BELLAIRS ELECTROMAGNETIC INSTRUMENT

Once the applicability of the $H_T$-curve for the accurate delineation of narrow conducting structures had been proved, the phase measurements became redundant, but they still had to be made with the two-coil method in order to obtain a sharp balance on the bridge circuit. Bellairs (1954) has designed an improved instrument for direct reading of the absolute magnetic field intensity from a stabilized primary current with a repeat accuracy of 0.1 decibels over a period of one hour. This instrument has the following advantages:

(1) The absolute intensity is read on a graduated ammeter. No balancing operation is necessary and the sliding contact on the rheostat, which gave much trouble on the Guelke instrument, is eliminated.

(2) Only one coil is required per pick-up. The coil and pick-up form a single unit and can be carried by the observer if necessary. The cables from coils to pick-up, which have been a constant source of trouble, are eliminated. Four laborers are no longer required for carrying the coils of the two pick-ups.

By using the new instrument, surveys have been speeded up appreciably, especially in difficult terrain with thick vegetation, and operating costs have thus been reduced.

## DIP DETERMINATION

The determination of the dip of a fault-zone or other structure located by the electromagnetic method is of importance, especially for the selection of borehole sites for water, since the vertical borehole has to be drilled to penetrate the narrow aquifer at the optimum depth.

Assuming that the current density on a cross-section through the narrow conductor is proportional to its conductivity, it is possible to determine the shape of the $H_T$ electromagnetic field across an assumed structure by the use of graticules. Standard curves can be constructed for this purpose which are similar to those obtained for gravity anomalies over assumed vertical or inclined ore bodies (Hedstrom, 1938) having either finite or infinite horizontal length. Some standard curves are given in Figure 3.

The dip of the structure is indicated by the asymmetry of the $H_T$-curve. Although the resistivity and thickness of fault-zones generally vary with depth it is often possible to get a qualitative or even quantitative indication of the dip.

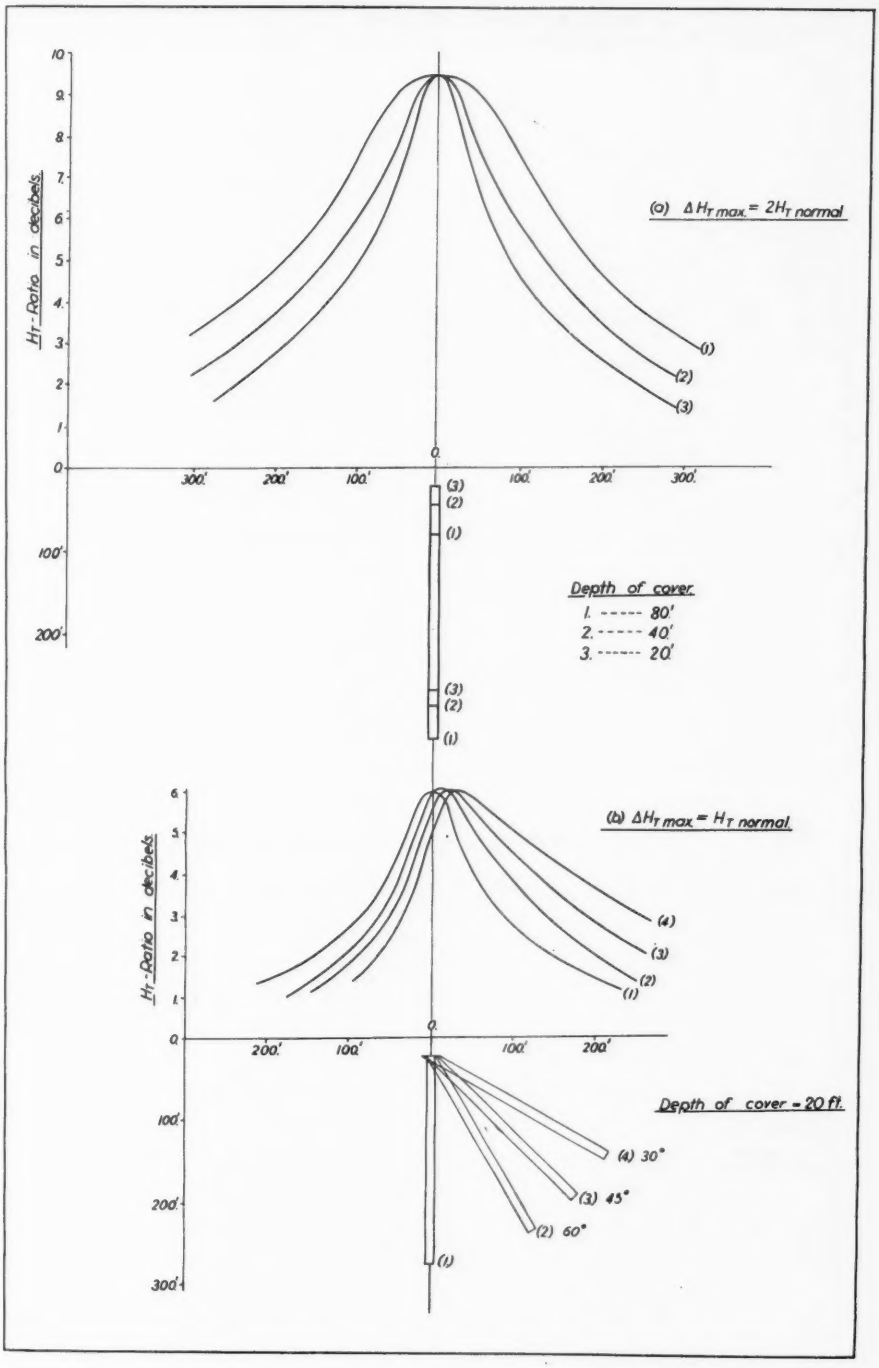
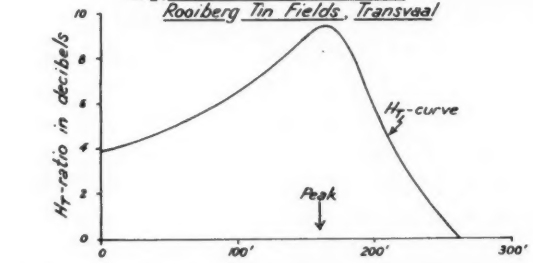
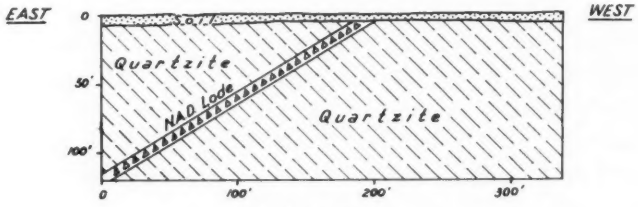



FIG. 3. Some standard $H_T$-curves, in decibels, for linear conducting structures with infinite horizontal length.

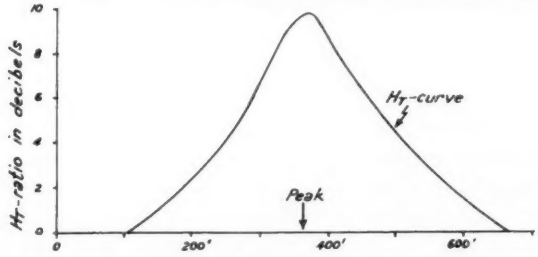
(a) $H_T$-curve across N.A.D. Lode
Rooiberg Tin Fields, Transvaal

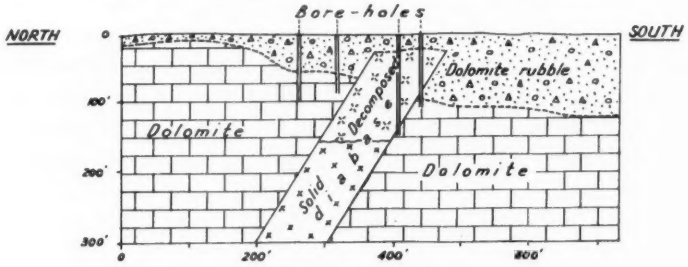



Geological Section

(b) $H_T$-curve across dyke, Swartkop Aerodrome, Pretoria

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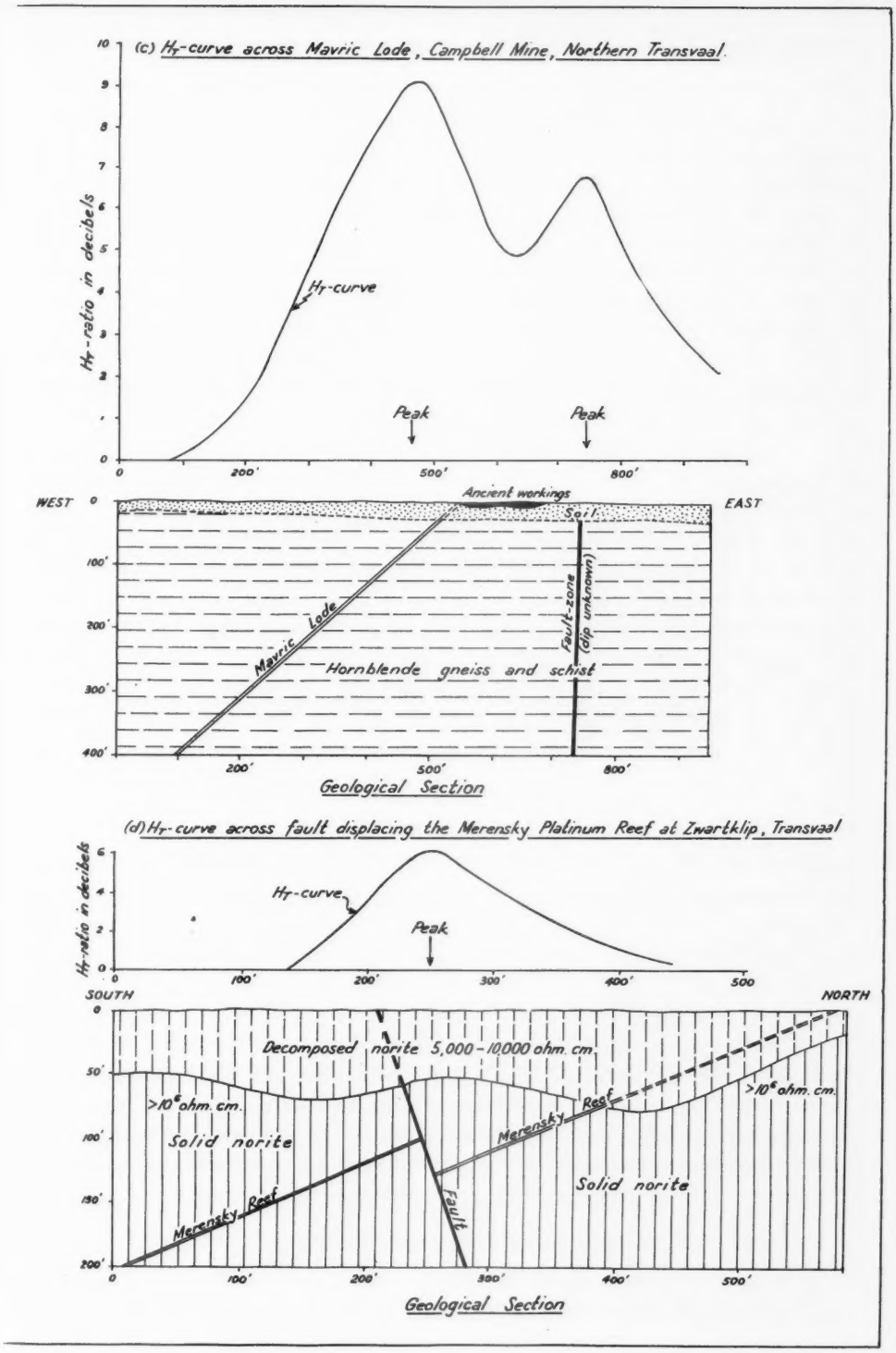


FIG. 4. Typical $H_T$-curves across linear conducting structures.

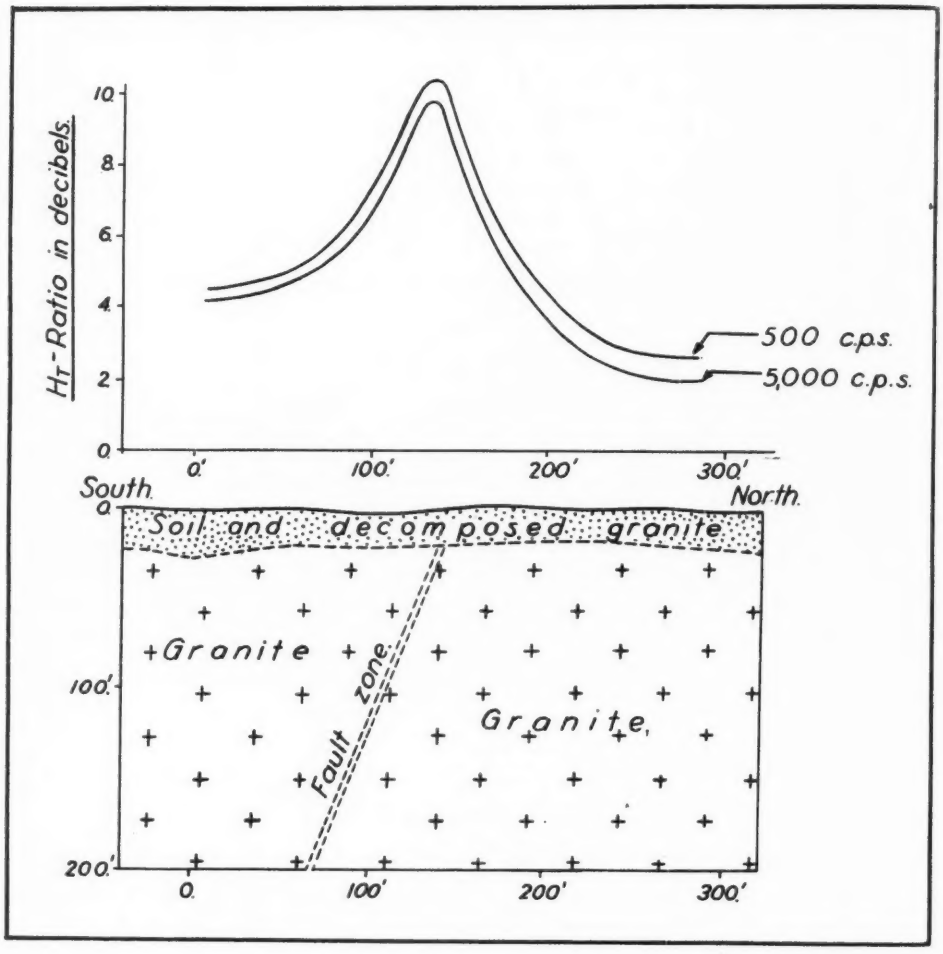


FIG. 5. $H_T$-curves for frequencies of 500 and 5,000 cycles per second, observed at Klipdrift 123, Pretoria district.

In Figure 4, dipping structures are indicated on the $H_T$-curves observed across the N.A.D. lode at the Rooiberg Tin Mine, Warmbaths district, and across the fault displacing the Merensky Platinum Reef on Zwartklip, Rustenburg district, both in the Transvaal. As dip-interpretation is dependent on the shape of the $H_T$-curve as a whole, such interpretations cannot be made where the limbs of the curve are distorted by superposition of other anomalies. This is illustrated by the $H_T$-curve across the Mavric-Lode at Campbell mine in Figure 4.

## DEPTH FACTORS

The peak of the $H_T$-curve is directly above a vertical conducting structure and is displaced some distance downdip from the sub-outcrop of an inclined

structure. The depth below the location of the $H_T$ peak at which the dipping structure will be reached is called the "weighted" depth of the structure. The "weighted" depth depends on the depth of homogeneous overburden, the variation in width and resistivity of the structure with depth, and, theoretically, on the frequency of the current used. The "weighted" depth of a fault is important for the accurate delineation of the structure and it can be estimated by comparison of the observed curves with standard curves. For ease of calculation, the $H_T$-observations are made in decibels. The standard curves are also plotted in decibels. It is necessary to know the ratio between the intensity of the peak of the anomaly and the intensity of the normal $H_T$-field and to use the appropriate standard curve for comparison.

It has been found that the "weighted" depths of steeply dipping structures vary between 20 ft and 100 ft and are approximately twice the depth of the homogeneous overburden.

Since the depth of penetration of the alternating current is, among other factors, a function of its frequency, a displacement of the peak of the $H_T$-anomaly across a dipping structure should on theoretical grounds be observed if the frequency is changed; use of such displacement for determining the dip of the structure was given consideration. Frequencies of 500 and 5,000 cps have been used for traverses over inclined fault planes in granite, but no displacement of the peak was observed (Fig. 5). The difference in depth of penetration in formations with resistivities of 10,000 to 30,000 ohm-cm is, therefore, negligible for those frequencies. Further tests are to be carried out with higher frequencies over structures with lower resistivities.

### EFFECT OF DISTANT EARTH-ELECTRODE ON CURRENT DISTRIBUTION AT SET-UP

It has been observed that if a set-up is laid out on a homogeneous or a horizontally layered formation, the current does not spread radially from the center-point, but is definitely drawn towards the ground electrode. This distortion of the $H_T$-field is clearly shown in Figure 6(a) on the curves for the circular traverses observed on Karroo sediments at Welkom, Orange Free State, where ground No. 1 and ground No. 2 were on opposite sides of the center-point.

For geological conditions where the current concentrates along a number of conducting zones in a high-resistivity formation, the position of the earth-electrode has practically no effect on the current distribution and the major peaks are not displaced by changing the position of that electrode. A typical $H_T$-curve across a number of closely-spaced conducting zones is given in Figure 6 (b).

### RESOLVING POWER OF $H_T$-CURVE FOR CLOSELY-SPACED STRUCTURES

As mentioned previously, one of the limitations of other field techniques, especially those based on the measurement of vertical intensitites, is the low

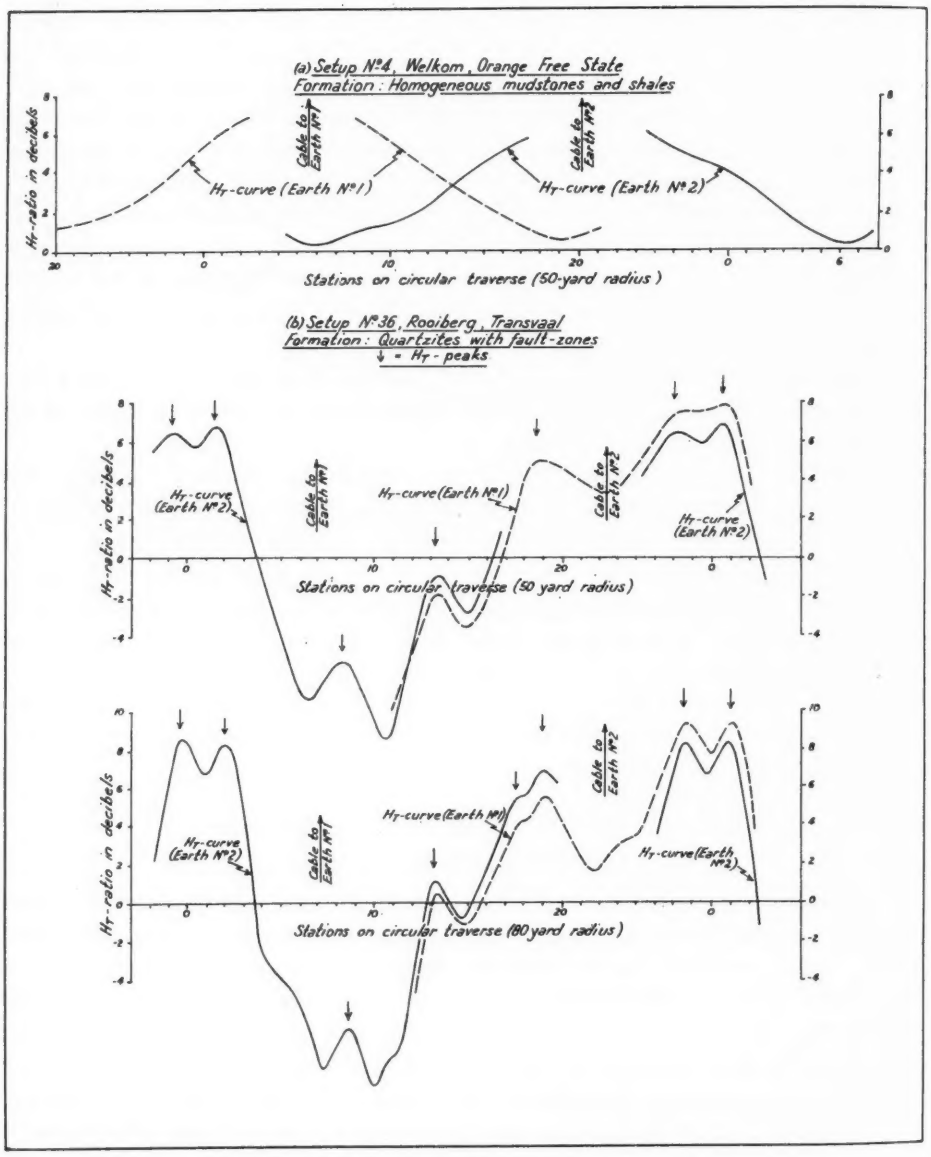
(a) Setup N°4, Welkom, Orange Free State
Formation: Homogeneous mudstones and shales
Hr-ratio in decibels
Cable to Earth N°1
Cable to Earth N°2
Hr-curve (Earth N°1)
Hr-curve (Earth N°2)
Stations on circular traverse (50-yard radius)
(b) Setup N°36, Rooiberg, Transvaal
Formation: Quartzites with fault-zones
↓ = Hr-peaks
Hr-ratio in decibels
Hr-curve (Earth N°2)
Cable to Earth N°1
Hr-curve (Earth N°1)
Cable to Earth N°2
Hr-curve (Earth N°2)
Stations on circular traverse (50 yard radius)
Hr-ratio in decibels
Hr-curve (Earth N°2)
Cable to Earth N°1
Hr-curve (Earth N°1)
Cable to Earth N°2
Hr-curve (Earth N°2)
Stations on circular traverse (80 yard radius)

FIG. 6. $H_T$-curves showing effect of position of distant earth-electrode.

resolving power for adjacent structures, due to the superposition of their anomalies. The result is that accurate interpretation, for position and dip, of data taken over such structures becomes practically impossible.

The accuracy of the interpretation of the $H_T$-curve for the position of a structure is dependent only on the accuracy with which the peak of the anomaly

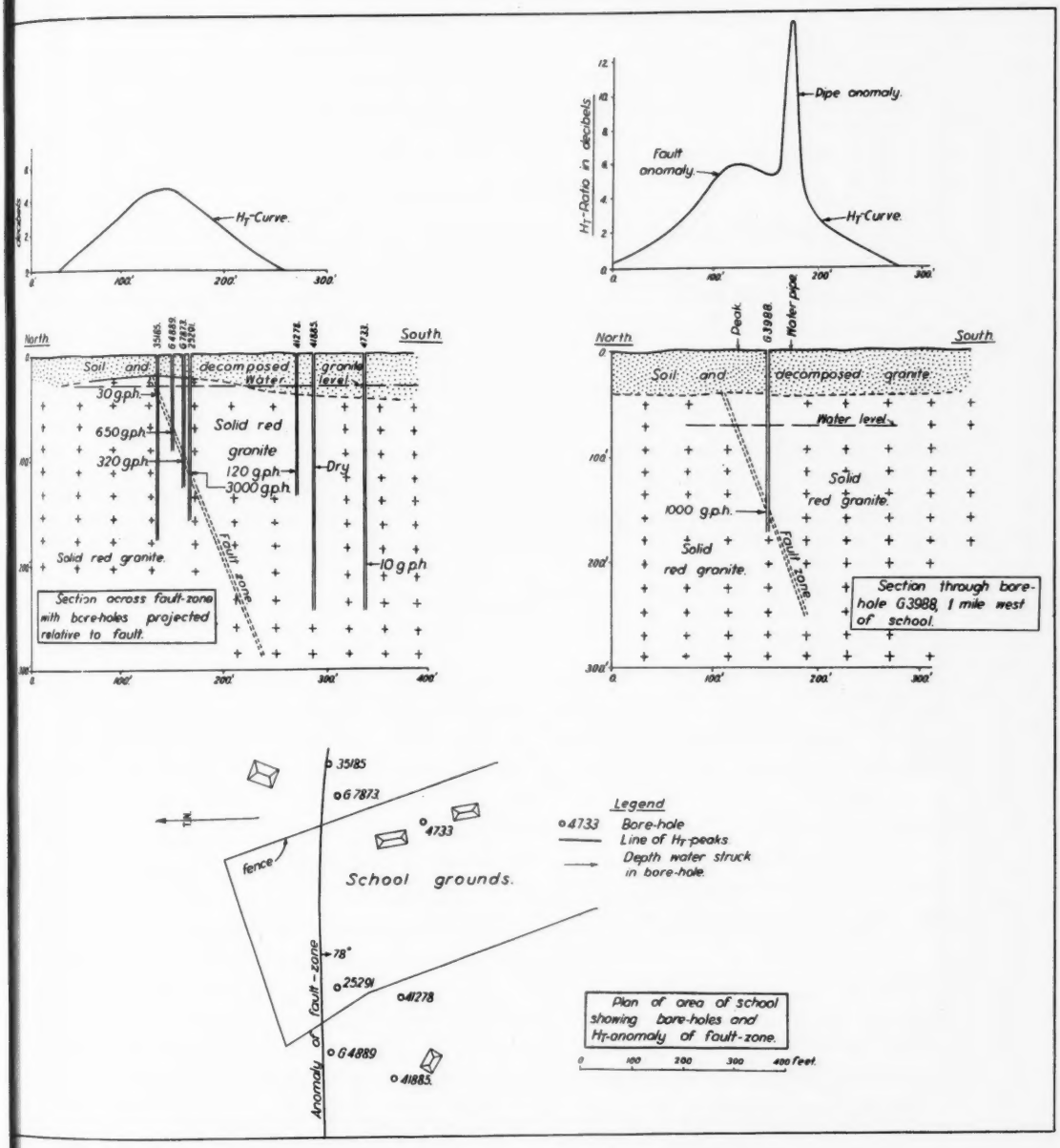


FIG. 7. Plan and sections showing existing boreholes and sites—G.3988, G.4889, and G.7873—selected on fault-zone, Klipdrift 123, Pretoria district.

can be determined. The displacement of the peaks by anomalies due to nearby structures is generally negligible and their positions can thus be established accurately even if the limbs of the anomalies are distorted.

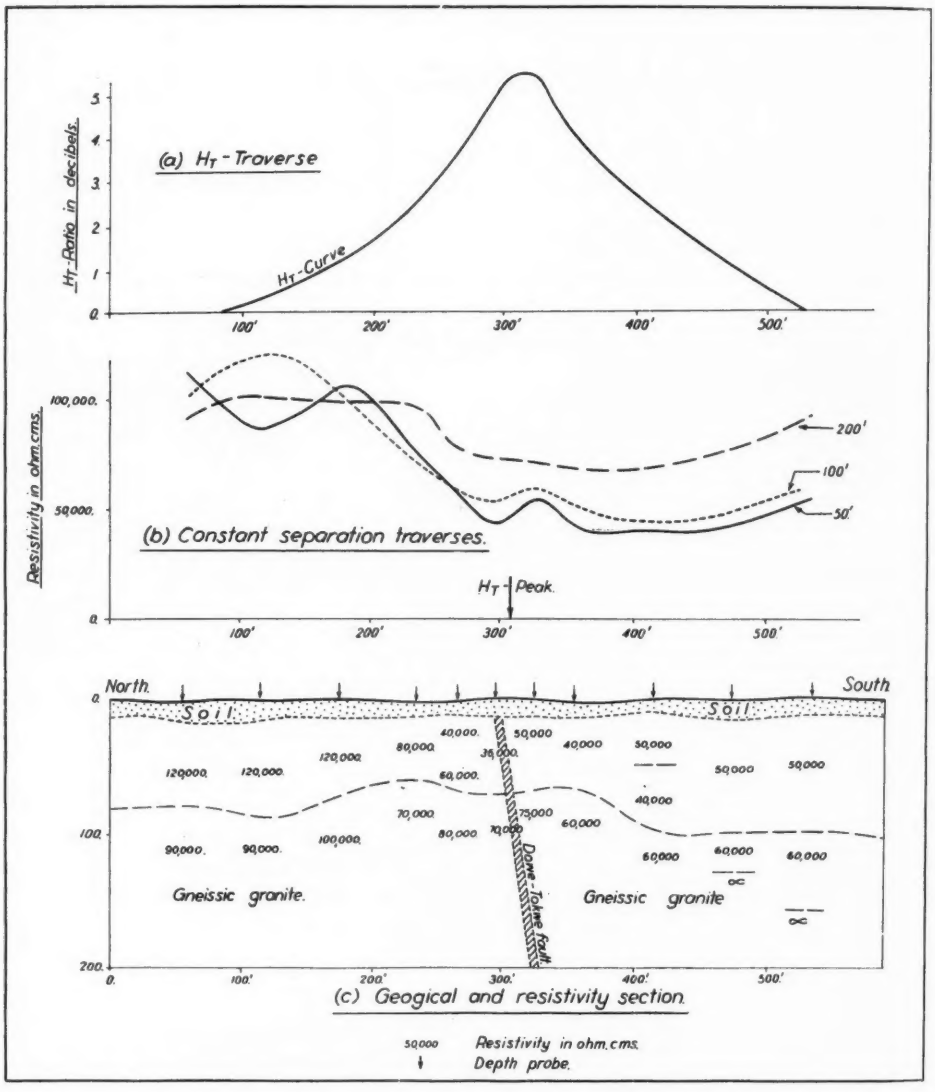


FIG. 8. Electrical survey of Dowe-Tokwe fault south of Messina, Northern Transvaal.

In areas where there is a network of fracture zones or small faults that may be economically mineralized, the $H_T$-curve will consist of a number of peaks and each one can be accurately plotted on the map and the network of conducting zones can thus be delineated. A typical $H_T$-curve of this type is shown in Figure 6 (b). This curve was obtained in the Rooiberg Tin Mining Area where mineralization is associated with numerous fault zones. The $H_T$-curve obtained across the Dowe-Tokwe fault (Fig. 2) shows the resolution of the anomalies into the major fault-zone and an ancillary fault 20 yards farther south.

The anomalies due to pipes and other shallow conductors can very easily be recognized by their narrow shapes. In Figure 7, the curve obtained on farm Klipdrift 123, west of the school, shows that anomalies due to the fault-zone and the water pipe, although superimposed, can nevertheless be interpreted accurately.

## SPEED OF SURVEYS

A field party consists of two observers and six native laborers. Set-ups and cables are laid out by the laborers. The observation of a circular traverse can be taken nearly as rapidly as the observer can walk around the circle, and the time required to complete a survey of a certain area is largely determined by the time required for laying out the stations. This time may vary considerably depending on the density and size of the vegetation. In open country it is possible to cover more than 50 acres per day.

Once an anomaly has been established, it can be traced by observations on small arcs across the peaks, and by the partial survey of additional set-ups along the strike. This detailing can be carried out at practically the same speed as is possible in tracing an anomaly by magnetometer.

## CONCLUSION

The electromagnetic technique described above has proved to be a very useful and efficient addition to the geophysical methods used by the Geophysical Branch of the Geological Survey of South Africa. Although it is possible to locate some faults by other methods, this method is the only one used at present by the Geological Survey for the accurate location of faults and similar narrow conducting structures.

The method has been applied in routine surveys for the location of (1) faults containing tin mineralization in the Rooiberg and Leeupoort Tin Fields, (2) faults associated with the copper mineralization in the Messina area, (3) lodes of arsenic and molybdenum ores in the Potgietersrust district, and (4) silver- and lead-bearing veins in the Pretoria and Springs districts.

The major application, however, has been for the selection of borehole sites in bedrock formations (Enslin, 1952). The method is used either in conjunction with resistivity measurements for the delineation of wider conducting zones which are vaguely indicated by the resistivity studies, or independently for locating narrow fractures or fault zones which have given no indications in resistivity surveys, as shown in Figure 8.

## ACKNOWLEDGMENTS

The Author wishes to express his sincere appreciation to those members of the Staff of the Geological Survey who have helped him with the investigations, and to Mr. A. Besaans, Principal Draftsman, Geological Survey, and his staff, for preparing the text-figures.

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# PATENTS

O. F. RITZMANN*

## GRAVIMETRIC PROSPECTING

*U. S. No. 2,695,165.* S. Hansen. Iss. 11/23/54. App. 7/14/50. Assign. Hughes Aircraft Co.

*Electromagnetic Accelerometer.* An accelerometer having a triaxial cross with six equal arms carrying magnets at their outer ends and suspended by current-carrying coils, relative displacement of the cross and coils being optically detected and automatically balanced by counterthrust from the coils whose current is indicated.

*U. S. No. 2,697,594.* A. N. Stanton. Iss. 12/12/54. App. 2/17/51.

*Acceleration Detecting Device.* An accelerometer having a solenoid suspended in the air gap of a permanent magnet by a diaphragm which is also one plate of a condenser connected to change the output of an oscillator, the output being rectified and fed back to the solenoid to produce an opposing force on the suspended system with the solenoid current measured.

## MAGNETIC PROSPECTING

*U. S. No. 2,692,970.* W. E. Tolles. Iss. 10/26/54. App. 9/2/44. Assign. U. S. A.

*Compensation of Aircraft Magnetic Fields.* A method of compensating the perm, induced, and eddy-current fields of a magnetometer-carrying airplane by determining their individual components along mutually-perpendicular axes through a series of maneuvers such that the magnetometer can measure identifiable components which are in turn compensated by coils on the plane.

*U. S. No. 2,694,793.* W. L. Martin. Iss. 11/16/54. App. 8/24/50. Assign. Bendix Aviation Corp.

*Device for Determining the Strength of a Magnetic Field.* A non-oriented magnetometer having three mutually-perpendicular flux-valves whose outputs are added vectorially by exciting two elements with a 45° phase shift between them, adding their outputs algebraically, and using this to excite the third element whose output is indicated.

*U. S. No. 2,695,384.* A. A. Stuart, Jr. Iss. 11/23/54. App. 11/1/49. Assign. Bendix Aviation Corp.

*Inductive Device of the Saturable Core Type Having Flux Regeneration Characteristics.* A saturable-core magnetic detector whose core has a central window through which opposing exciting windings are wound and having a second-harmonic tuned output winding around the ends of the core, the circuits being adjusted in phase to that peak output current occurs during saturation of the core.

*U. S. No. 2,696,602.* C. R. Evans. Iss. 12/7/54. App. 7/6/44. Assign. U. S. A.

*Compensated Magnetometer.* A detector of short-duration magnetic anomalies having a flux valve which is automatically compensated for slow changes in the ambient field by a second flux valve mechanically aligned with it and with the output of the second flux valve rectified, filtered, and fed back to both flux valves as a compensating current.

*U. S. No. 2,697,186.* W. C. Anderson. Iss. 12/14/54. App. 7/31/44. Assign. U. S. A.

*Compensator for Induced Magnetic Fields.* A system for compensating the magnetic field induced in ferromagnetic members of an aircraft having three mutually-perpendicular flux-valve elements each of whose output contributes to the current in three mutually-perpendicular compensating coils,

* Gulf Oil Corporation, Patent Department, Pittsburgh, Pa.

each component being separately adjusted by an attenuator until the residual total induced field is minimized.

### RADIOACTIVITY PROSPECTING

*U. S. No. 2,692,339.* E. Franklin. Iss. 10/19/54. App. 9/2/47 and 8/23/48. Assign. The National Research Development Corp.

*Gamma-Ray Detector.* A gamma-ray detector having a Geiger-Müller tube whose anode is connected to high voltage through a resistor and whose cathode also has a resistor whose potential triggers a cold-cathode discharge tube in an integrating circuit.

### SEISMIC PROSPECTING

*U. S. No. 2,691,939.* A. J. Hintze. Iss. 10/19/54. App. 9/12/49. Assign. Phillips Petroleum Co.

*Apparatus for Planting an Explosive Charge Below the Surface of the Earth Beneath a Body of Water.* A device for planting a seismic prospecting charge under water with a submersible air hammer with driving rod which forces the charge into the bottom sediments and is released by upward movement of the hammer shearing a pin between the hammer and the charge.

*U. S. No. 2,692,306.* J. L. Hathaway and R. E. Lafferty. Iss. 10/19/54. App. 12/8/49. Assign. Radio Corp. of America.

*Audio Amplifier with Plural Automatic Gain Controls.* An audio amplifier having automatic gain control in which rectified output signal is applied as negative bias to a push-pull stage and input signal above a threshold is rectified and applied through a gas-discharge tube as positive bias to the same tubes, so that normal avc action is overbalanced at extremely large signals.

*U. S. No. 2,693,245.* J. E. Hawkins. Iss. 11/2/54. App. 1/10/49. Assign. Seismograph Service Corp.

*Seismic Wave Generating Apparatus.* An above-ground explosive array having a series of Primacord lines stretched between supports and detonated at the midpoint which is elevated above the end points so that the wave front strikes the ground under the line simultaneously.

*U. S. No. 2,693,862.* F. Rieber. Iss. 11/9/54. App. 10/11/48. Assign. Geovision Inc.

*Method of and Apparatus for Displaying Geophysical Data.* A system for portraying reflections in reflection shooting in which the seismometer signals modulate the intensity of beams in a multibeam c-r tube, the beams being made to traverse loci of reflection points so that coincident modulations of intersecting traces are additive and show reflecting surfaces.

*U. S. No. 2,693,908.* A. J. A. Favre. Iss. 11/9/54. App. 8/8/46 and 8/26/47. Assign. Office National d'Etudes et de Recherches Aeronautiques.

*Apparatus for the Analysis of a Record and the Indication of the Correlation Factor.* A record-analyzing system in which the record is reproduced at two spaced points behind the recording point and the two reproductions used for quadrature deflection of a c-r beam whose pattern area may be observed.

*U. S. No. 2,695,211.* G. K. Guttwein and F. K. Priebe. Iss. 11/23/54. App. 5/31/51. Assign. U. S. A.

*Recording Accelerometer.* A direct recording mechanical accelerometer having a magnet on the suspended system which records on one half of a moving magnetic tape and a time-actuated magnet which records on the other half of the tape.

*U. S. No. 2,696,592.* M. O. Petroff. Iss. 12/7/54. App. 5/5/51. Assign. Stewart-Warner Corp.

*Vibration Pickup.* A variable air-gap suspended armature type of reluctance vibrometer having liquid damping and spring arms with several loops to achieve low natural frequency.

*U. S. No. 2,696,891.* J. Neufeld. Iss. 12/14/54. App. 11/26/51.

*Seismic Surveying.* A seismic prospecting system in which the receiving point record and a record made close to the shot point are transformed into graphs of amplitude and phase against frequency and the earth admittance function determined, artificially computing the amplitude and phase curves which would be obtained at the receiving point by an idealized impulse or unit function acting on the earth admittance, and converting the resulting curves into a seismogram which would result from the idealized shot.

*U. S. No. 2,696,972.* S. D. Howe. Iss. 12/14/54. App. 1/26/51. Assign. The Atlantic Refining Co.

*Portable Earth Drill.* A portable shot-hole drill for marshy areas having a frame supported by two men and a chuck and rotary table driven by a flexible shaft to a portable gasoline engine.

*U. S. No. 2,697,648.* R. B. Kerr and R. K. Roberts. Iss. 12/21/54. App. 8/11/49. Assign. Socony-Vacuum Oil Co., Inc.

*Timing System for Recorders.* A seismograph timing system in which a vibrating-reed light chopper is released by the time-break impulse and timing lines are recorded on the tape at a point displaced from the galvanometer recording point by a distance corresponding to the release delay, every tenth line also being numbered by an independent light beam passing through a film with numbers and advanced by pulses from a frequency-dividing circuit.

*U. S. No. 2,697,822.* O. H. Schuck and L. G. S. Wood. Iss. 12/21/54. App. 8/14/44. Assign. U. S. A.

*Sound Detecting and Indicating System.* An echo-sounding apparatus having an azimuthal array of magnetostrictive receivers which are connected to a continuously-rotating switch and a c-r tube with spiral sweep, the rotation of the c-r beam being synchronized with rotation of the switch and radial sweep of the beam started with the transmitted sound impulse.

WELL LOGGING

*U. S. No. 2,690,672.* G. B. Thomas. Iss. 10/5/54. App. 4/15/49. Assign. Signal Oil and Gas Co.

*Inertial Marking Device for Subsurface Instruments.* A mechanically-recording well-logging or surveying device in which the stylus moves across a stationary chart in proportion to the parameter being measured and a resiliently-mounted inertia element marks the record whenever the instrument is accelerated or jarred.

*U. S. No. 2,690,673.* G. B. Thomas. Iss. 10/5/54. App. 1/24/49. Assign. Signal Oil and Gas Co.

*Inertial Marking Device for Subsurface Gauges.* A mechanically-recording well logging or surveying device in which the record chart is resiliently mounted so that an identifying mark may be made along the record trace by accelerating or jarring the instrument at a known depth, the pen being moved in proportion to one parameter and the chart being driven by a clock or in proportion to a second parameter.

*U. S. No. 2,690,674.* G. B. Thomas. Iss. 10/5/54. App. 11/14/49. Assign. Signal Oil and Gas Co.

*Inertial Marking Device for Subsurface Gauges.* A mechanically-recording well temperature and pressure recorder having a pressure-actuated pen drive and a temperature-actuated chart drive, with the chart resiliently mounted so that an identifying mark may be made on the record curve by jarring the instrument at a known depth.

*U. S. No. 2,691,109.* G. G. Bernard. Iss. 10/5/54. App. 12/31/51. Assign. The Pure Oil Co.

*Logging Oil Wells.* A method of logging the cation-exchange property of formations by contacting them with a material capable of exchanging cations with the clays and having a radioactive element in its cation, removing the excess radioactive material from the well and then running a radioactivity log.

*U. S. No. 2,691,422.* G. C. Summers and R. A. Broding. Iss. 10/12/54. App. 11/22/50. Assign. Socony-Vacuum Oil Co., Inc.

*Selective Pulse Acoustic Well Logging Apparatus.* An acoustic logging apparatus in which interference from sound through the well fluid is eliminated by controlling bias on the receiver amplifier with a monostable multivibrator which is triggered by the transmitted pulse and which cuts off the amplifier after a time interval to admit only the wave through the formations.

*U. S. No. 2,691,741.* G. Swift. Iss. 10/12/54. App. 11/30/50. Assign. Well Surveys, Inc.

*Detector for Neutron Well Logging.* A neutron-logging detector having a shield of tungsten sintered with copper in order to reduce sensitivity to scattered gamma rays with respect to gamma rays produced by neutron interaction in the formations.

*U. S. No. 2,691,757.* G. B. Salimbeni. Iss. 10/12/54. App. 9/20/52.

*Electrical Well Logging.* A method of self-potential logging in which an ordinary s-p log is taken and a non-ionized organic oxidant then added to the well fluid and a second s-p log taken and compared with the original log.

*U. S. No. 2,692,755.* T. J. Nowak. Iss. 10/26/54. App. 2/19/51. Assign. Union Oil Co. of Calif.

*Process and Apparatus for Logging Boreholes.* A radioactivity mud-logging method in which the natural radioactivities of the drilling mud entering and leaving the hole are measured, the cuttings separated from the mud and their natural radioactivity measured, and the cuttings irradiated with neutrons and their induced radioactivity measured.

*U. S. No. 2,692,949.* J. D. MacKnight. Iss. 10/26/54. App. 12/29/51. Assign. The Texas Co.

*Combination Radioactivity Borehole Logging.* A radioactivity logging apparatus having a long housing with a radium-beryllium source fixed at its lower end and a scintillometer detector which may be raised and lowered within the housing, a log being taken over an interval by raising the outer housing with the detector at the top, lowering the outer housing with the detector near the bottom, and then raising the outer housing with the detector shielded on all sides by a lead cylinder.

*U. S. No. 2,694,179.* J. E. Walstrom. Iss. 11/9/54. App. 3/13/50. Assign. California Research Corp.

*Method for Electrical Well-Logging.* A method of self-potential logging in which two logs are taken with different known resistance in the external voltmeter circuit so that the internal resistance of the formations can be computed.

*U. S. No. 2,694,461.* J. L. Martin. Iss. 11/16/54. App. 11/12/49. Assign. The Atlantic Refining Co.

*Apparatus for Acoustic Logging.* An acoustic logging apparatus having an acoustic source and receiver separated by a rubber connector to dampen direct waves, the source-receiver spacing being small enough to eliminate the wave refracted through the borehole wall, and measuring the amplitude of the reflected energy received.

*U. S. No. 2,694,791.* M. Schlumberger. Iss. 11/16/54. App. 3/17/50 and 12/18/50. Assign. Societe de Prospection Electrique Procedes Schlumberger.

*Method and Apparatus for Investigating Earth Formations Traversed by Boreholes.* An apparatus for detecting the presence of oil in a borehole wall and having a pad of material that is water repellant but which has an affinity for oil and with electrodes embedded in the pad so that when oil is contacted the resistance between the electrodes increases.

*U. S. No. 2,695,820.* F. F. Segesman. Iss. 11/30/54. App. 2/17/53. Assign. Schlumberger Well Surveying Corp.

*Carrier Pad for Use in Boreholes.* An electric logging electrode which is made to contact the bore-

hole wall over a substantial azimuthal region by having its radius of curvature automatically adjusted by a linkage or cam on the arms which urge it against the borehole wall.

*U. S. No. 2,696,112.* C. O. Griffith. Iss. 12/7/54. App. 11/7/52. Assign. Standard Oil Development Co.

*Apparatus for Indicating Entry of Fluids in Well Bores.* A long cylindrical cage having oil- or water-soluble bodies distributed along its length, the entry of oil or water at various levels being determined by the amount of material lost.

*U. S. No. 2,697,941.* T. V. Moore and R. R. Thompson. Iss. 12/28/54. App. 9/14/50. Assign. Standard Oil Development Co.

*Determining Zones of Fluid Flow in a Well Bore.* A method of flow logging in which the volume of vertical flow is measured by a vane-type flowmeter and a thermometer also measures the temperature rise produced in the fluid by an electric heating element.

*U. S. No. 2,697,942.* P. O. Engelder. Iss. 12/28/54. App. 12/17/51. Assign. Oil Well Water Locating Co.

*Device for Measuring Velocity of Flow of Fluid in Wells.* A well flowmeter having a spiral vane on an axial magnetostrictive core which is torsionally stressed in a coil connected to an oscillator circuit whose frequency change is indicated.

### MISCELLANEOUS

*U. S. No. 2,691,135.* W. M. Wooding. Iss. 10/5/54. App. 3/26/52. Assign. American Cyanamid Co.

*Automatic Instrument for Determining Permeability of Porous Dielectrics.* An instrument for measuring the time required for an electrically-conducting fluid to penetrate through a porous material by recording the time interval from the instant the fluid establishes conductivity between two electrodes on one side of the material to that of establishing conductivity to an electrode on the other side of the material.

*U. S. No. 2,691,298.* E. L. Cook. 10/12/54. App. 11/3/51. Assign. Socony-Vacuum Oil Co., Inc.

*Filter Cake Thickness Gauge.* A device for measuring filter-cake thickness and which has a circular knife edge to cut through the filter cake and confine it and an inner plunger which rests on top of the filter cake with a micrometer screw to indicate the distance between the knife edge and the plunger.

*U. S. No. 2,693,104.* H. J. Welge and L. A. Rapoport. Iss. 11/2/54. App. 10/27/49. Assign. Standard Oil Development Co.

*Measuring Relative Permeability of a Porous Medium to a Wetting Phase.* A method of measuring relative permeability of a core sample in which mercury or Woods metal is forced into the core to simulate the presence of a non-wetting phase, and the permeability is measured with air to simulate the wetting phase.

*U. S. No. 2,695,750.* C. F. Kayan. Iss. 11/30/54. App. 12/7/45.

*Method and Apparatus for Analyzing Flow Networks.* An electrical analogue computer for a pipeline network in which voltage corresponds to the force producing the flow and resistances correspond to the flow branches with servomotors maintaining a fixed relation between the resistance in each branch and the current through the network.

*U. S. No. 2,696,676.* R. T. Cloud. Iss. 12/14/54. App. 6/27/50. Assign. North American Geophysical Co.

*Apparatus for Pendulum Compensation against Acceleration Induced Components of Force.* A system for counterbalancing deflections of a pendulum due to acceleration of the vehicle on which it is

mounted by having a flywheel driven by the vehicle through a torsion shaft, the torsion being detected and applied to the pendulum as a counterbalancing force.

*U. S. No. 2,697,828.* K. O. Heintz. Iss. 12/21/54. App. 12/29/49. Assign. Standard Oil Development Co.

*Reflector for Electromagnetic Waves.* A freely-rotating radar reflector having two or more trihedral reflectors at the ends of horizontal arms carried on a vertical spindle with the reflectors also serving as wind cups to rotate the assembly.

*U. S. No. 2,698,133.* F. W. Bubb. Iss. 12/28/54. App. 1/8/51. Assign. Phillips Petroleum Co.

*Mechanical Simulator for Downhole Pumping Systems.* A mechanical analogue of a deep-well pumping system in which a series of flywheels represent sections of the oil column, tubing, and sucker rod string, and the torques in the shafts represent stresses in corresponding elements, and dampers connected between the flywheels represent friction, the simulated oil column being provided with one-way clutches to prevent simulation of tension.

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# REVIEWS

## REVIEWS COMMITTEE

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*Monomolecular Layers*, Harry Sobotka, AAAS, Washington, D. C., 1954. 207 pp., $4.35.

Originally a somewhat obscure and isolated specialty in the field of scientific investigation, the study of the physics and chemistry of assemblies of molecules extending in only two dimensions has, in the last twenty years, attracted the interest of investigators in many apparently unrelated endeavors. Indeed, all those whose studies lead them to consider the behavior of systems involving interfaces and phase boundaries find themselves confronted eventually with the same basic questions. And so it is that the biologist, the biochemist and the physiologist, the physical, colloid, organic, and analytical chemists, industrial researchers and engineers in the fields of chemical processing, textiles, production and refining of petroleum, medicine, mining, and paint technology, all converge from their separate and diversified backgrounds upon the subject of monomolecular layers.

This book is a collection of nine papers selected to describe recent progress in the development of the knowledge of monomolecular layers. Some of the papers were presented as a symposium on Monomolecular Layers at the Philadelphia meeting of the American Association for the Advancement of Science in December, 1951.

The first two papers are concerned principally with improvements in the equipment and techniques for the accurate measurement of surface pressures and molecular areas of insoluble monolayers, the two-dimensional counterparts of pressure and volume. Such measurements are valuable in the study of biochemical reactions, and provide another method for the determination of molecular weights of certain classes of compounds. Discussed in detail are the conditions under which reliable values of the molecular weights of proteins can be obtained by these procedures.

The third and fourth papers discuss films formed at solution-air interfaces by adsorption of detergents from aqueous solution. The first of these reviews the bulk thermodynamic properties of such solutions and the phenomenon of solubilization, and then presents original data on both "equilibrium" and "short time" surface tensions. Measurements of surface viscosity by an adaption of the Couette-type rotational viscometer demonstrate deviations from Newtonian character of detergent films as a result of surface-active impurities. The air permeability of the films, an important factor in foam stability, was measured and found to be decreased by the presence of the surface-active impurities. The second of the papers devoted to adsorption at the air-water interface discusses in detail the application of the radiotracer technique to the investigation of the "molecular anatomy" of the surface layer.

It was found that under different conditions the detergent may be absorbed as a monolayer or as a multilayer. Data on the adsorption of mixtures of surface active agents are reported, and observations were made of the absorption of ions beneath a charged monolayer.

The fifth and sixth papers in the volume are concerned with monolayers on solids. The first of these continues the discussion of the utility of the radiotracer technique and presents data on surface diffusion in monolayers on solid surfaces. Adsorption of hydrophobic monolayers on solids from aqueous solution is the subject of the second paper devoted to solid substrates. This topic has many applications, including ore flotation, inhibition of corrosion, and the deposition of water-repellent coatings.

The seventh paper in the collection surveys the small fund of knowledge currently available concerning the properties of films at oil-water interfaces.

The study of chemical reactions in monolayers provides the subject of the last two papers in the volume. The first of these involves studies of reactions in monolayers on liquid and on solid surfaces, and the last discusses the changes in chemical equilibrium and in reaction rates in monolayers which result from changes in the electric potential difference existing between the surface and the bulk, or from, what is its equivalent, changes in the differences in ion concentrations existing between the surface and the bulk.

This book is not intended for the layman, nor is it designed to provide the student with a comprehensive background in the subject, but is a volume which will be of value primarily to the worker in some aspect of surface chemistry or physics as a means of keeping pace with recent developments in other aspects of his field. However, the serious reader with a technical background may find this book a curious and interesting excursion into a two-dimensional realm which is known at the present mostly by conjecture, hypothesis, and assumption, and in which there are many challenging riddles yet to be solved.

W. M. McCardell
Humble Oil & Refining Co.
Houston, Texas

*Principles of Geomorphology*, William D. Thornbury, John Wiley & Sons, Inc., New York, 1954, 618 pp., $8.00.

Considering the number of geomorphology texts available, one might ask: "Is this book necessary?" I believe it definitely is. "Principles of Geomorphology" is thoroughly up-to-date, containing the most recent geomorphic information available. Furthermore, the author's presentation fully reflects modern trends in geomorphology. Emphasis in the book is on principles rather than on encyclopedic description of landforms; thus, the reader should gain sound understanding of the origin and significance of landforms. A section not found in other texts deals with practical applications of geomorphology. This should do much to dispel the belief of some that geomorphology is merely an academic study of scenery.

The book can be divided into three main parts. The first (Chapters 1–2), contains general material relating to the history of the development of geomorphic thought and fundamental concepts. The main body of the book (Chapters 3–20) is devoted to geomorphic processes and resultant landforms. New or more adequate material than that in other available texts is presented concerning climate, soils, solifluction, and the topography of ocean floors. The traditional subjects of weathering and mass wasting, running water, ground water, waves, wind, glaciers, and their associated landforms are not slighted. The last part of the book consists of a chapter on tools of the geomorphologist and a concluding chapter on practical applications of geomorphology. Where geomorphic problems exist, the author treats them as such and discusses different explanations which have been proposed. The style of the book is clear and readable and its illustrations are good.

The author's belief that "world landscapes cannot be properly interpreted unless the many complex factors which have influenced their evolution is fully appreciated" is worthy of attention. The Davisian Cycle of erosion, which includes youth, maturity, and old age, when applied too enthusiastically may give an overly simple interpretation of landscapes. The author holds that structure, proc-

ess, and stage are important in the understanding of landscapes; however, a given landscape may not be the result of a single cycle but instead the complex product of several cycles involving more than one geomorphic process. Also, the influence of climate, exhumed topography, and geologic and climatic changes of the Pleistocene must be considered in any interpretation of the topography of an area.

The only weakness in the book, from my point of view, lies in the rather brief treatment of the dynamics of the geological agents. If streams, glaciers, wind, and waves are of importance in the development of landforms, then a knowledge of how these agents act to produce landforms is an important part of geomorphology. Structural geologists have not written off the forces of crustal deformation as outside their field. This criticism is not leveled at this book in particular, because no available geomorphic texts gives adequate treatment of this subject.

Geologists and geophysicists in petroleum exploration will find *Principles of Geomorphology* a valuable reference book. It provides an up-to-date understanding of landforms which in turn affords better appreciation of structure and lithology in an area under investigation.

BRAINERD MEARS, JR.
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*Magnetic Variometers of the Schmidt Type*, J. McG. Bruckshaw, Hilger & Watts, Ltd., London, 1954, 115 pp.

The author in the preface defines the scope of this book as a handbook designed to avoid unnecessary delays to field work when essentially minor repairs to the instrument are needed. Consequently a major portion of this book concerns itself with a rather detailed discussion of such topics as, "Maintenance and Adjustments," and "The Magnetometer in the Field," as well as general instructions for calibrating the magnetometer, both with and without auxiliary magnets.

The remaining information deals primarily with a description of the basic principles of magnetic prospecting and the results, taken from the literature, of a number of magnetometer surveys. A book of this type is not only useful to the magnetometer operator in the field, but should prove most helpful to university students enrolled in a geophysics laboratory or field course.

RICHARD A. GEYER

"Notes on the Problems on the Motion of the Surface of an Elastic Solid Produced by a Linear Source," H. Honda and K. Nakamura, *The Science Reports of the Tohoku University, Geophysics*, v. 5, p. 58–66, 1953.

The authors consider the harmonic integral solutions to the boundary-value problem of a line source on a distance $a$ from the surface of a semi-infinite elastic solid having a free boundary. The singular integrals as developed by Lamb[1] and Nakano[2] are of the form (ref.: Lamb's equation (52) and Nakano's equation (98)):

$$I = \int_{-\infty}^{\infty} G(q, h, k, \alpha, \beta) e^{i(qx - \alpha a)} dq \cdot e^{i\omega t} \tag{1}$$

where

$$\omega = 2\pi \text{ (frequency)}, \qquad h = \frac{\omega}{V_c}, \qquad k = \frac{\omega}{V_s}, \qquad V_c = \sqrt{\frac{\lambda + 2\mu}{\rho}}, \qquad V_s = \sqrt{\frac{\mu}{\rho}}$$

$$\alpha^2 \equiv q^2 - h^2, \qquad \beta^2 \equiv q^2 - k^2.$$

$q$, the variable of integration, is formally related to that of the Fourier exponential integral. The authors then argue that a particular transformation of variable given by

$$q = h \sin w \tag{2}$$

allows one to make evaluations of integrals of the type (1) in the complex $w$-plane which are exactly the same as those obtained by Lamb and Nakano in the $q$-plane except that the present authors obtain a Rayleigh wave contribution to the solution which does not require further modification in order to have the property of a traveling wave.

It is this reviewer's opinion that the transformation (2), which the authors attribute to Sakai,[3] represents simply a return to the picturesque $w$-plane of Debye[4] and Sommerfeld[5] with its mountains, valleys, and cols which has been the subject of so many papers. To see this we need only consider the line source in polar coordinates $(r, \theta)$ as a superposition of plane waves of the form $e^{-i(hx-\omega t)} \equiv e^{-ihr\cos(\theta-\phi)+i\omega t}$ taken over the complex angle $\theta$ that the plane wave normal makes with the $x$-axis. We make use of the relation:

$$\left.\begin{aligned} z &= r\sin\theta \\ x &= r\cos\theta. \end{aligned}\right\} \tag{3}$$

Then, following Sommerfeld[5] it may be shown that

$$iH_0^{(2)}(hr)\cdot e^{i\omega t} = \frac{i}{\pi}\int_{-\pi/2-i\infty}^{\pi/2+i\infty} e^{-ih(|z|\cos\phi+|x|\sin\phi)}d\phi\cdot e^{i\omega t} \tag{4}$$

does indeed have the physical properties of an outgoing cylindrical wave motion at large distances. Now, if one introduces the new variable $q$ by

$$q = h\cos\phi, \tag{5}$$

(4) becomes

$$= \frac{1}{\pi}\int_{\Gamma}\frac{e^{h\alpha|z|-iqx}}{\alpha}dq\cdot e^{i\omega t} \tag{6}$$

with all quantities defined as in (1). The contour $\Gamma$ is a gamma-function type of contour and easily distorts into $[-\infty, \infty]$. Using (6) as a guide one can construct integral solutions which satisfy various boundary-value problems such as that of Lamb and Nakano. These will be of the form (1) if we take $q\to -q$. Thus we see that the variable of integration as used by Lamb and Nakano is essentially that of the cosine of the angle that the normal of the elementary plane waves of integrand makes with the $x$-axis and that the transformation (2) simply takes us to the plane of the complementary angle to $\phi$. The transformation from $(\pi/2)-\phi$ to $\phi$ is rather trivial. It is interesting to note that when an interface is placed at $z=f$, $\phi$ will be equal to the angle of incidence (with respect to interface normal) and we can consider our integral representation as a sum over all such plane waves arriving at the interface.

Contrary to the implication expressed by the authors, it is not the transformation (2) which enables the Rayleigh wave contribution to appear in its proper form, but rather the fact that the authors did not make use of the Cauchy concept of the principal value of an integral as did Lamb and Nakano. One could just as easily arrive at the correct form for the Rayleigh wave contribution by remaining in the $q$-plane as was done by Lapwood.[6]

Finally, it should be pointed out that two much more modern approaches than the use of (2) exist for evaluating integrals of the type (1). Both of these methods are based on the separation from $G$ in (1) of that part which is exponential in form. The complete exponent of the integrand is then transformed to a new $u$-plane. The first method is due to Ott and Van der Waerden[7] and is based on the transformation of the exponent to the form $-\lambda u$ where $\lambda$ is a large, positive, real parameter. The contour in the $u$-plane is then distorted about the branch cuts and contours which are taken to resemble that of the asymptotic evaluation of the gamma-function; in fact, the branch cut contributions appear as asymptotic expansions in such gamma-functions of half-integer arguments. The second method, that of L. Cagniard,[8] introduces the Laplace transform variable "$S$" by $s=i\omega$ and the exponent is then transformed to $-su$. The coefficient of $e^{i\omega t}$ in (1) is interpreted as the transform of the response to a "step-function in time" line-source. The solution follows after proper distortion of the contour and identification of the variable $u$ with the time $t$. It was pointed out to this reviewer some time ago by P. Hazebroek[9] that the method of Cagniard will yield the exact solution in a closed

integrated form of the Lamb-Nakano integral and in fact of any plane layer problem involving a line-source. W. Garvin[10] has since made some numerical calculations on the Lamb-Nakano problem utilizing the method of Cagniard.

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*The Fundamentals of Electric Log Interpretation*, M. R. J. Wyllie, Academic Press, Inc., September 7, 1954, 107 p., $3.60.

This little book deals very clearly with the fundamentals of electric logging. For one thing, it is up to date, a feature which is very valuable for the many people engaged now in electrical logging and the interpretation thereof. Moreover, it is an intelligent symposium of the literature on the subject, which is now quite abundant, disseminated, and not always either reliable or understandable. It is indeed an excellent primer on the subject, and one that geologists and petroleum engineers should have in their libraries if they are called upon to deal regularly with the subject in question.

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Houston, Texas

*Nuclear Geology*, Henry Faul, Ed., John Wiley and Sons, New York, 414 pp., 1954, $7.00.

The efforts of a large group of experts are included in this timely publication. Much of the material has appeared elsewhere in separate papers, but this volume collects the individual results into a rather well-knit book that should be of immediate interest both to geologists and geophysicists in view of the accelerated pace of nuclear development. The material starts with an introduction into fundamental considerations, continues with a broad survey of the distribution of radioactive minerals, and deals specifically with the effects of these minerals in such diverse aspects as earth heat, radiation damage, the origin of petroleum, geophysical exploration, and the age and origin of the earth. A capsule evaluation of this material is that it gives a good, dependable background to those geophysicists who are engaged in nuclear geology, but that it falls short of containing much information that has genuinely direct applicability to the prospecting for radioactive minerals.

The first chapter gives a good summary of basic units and definitions, which are essential to the understanding of the subject. Therefore, the material of this chapter must be comprehended. It goes beyond the unit and definition stage into the construction and operation of counters and laboratory techniques for assaying radiometric minerals.

The chapters on the distribution of radioactive minerals, principally uranium and thorium, are disappointing because of a rather academic attitude toward the problem. By this, it is meant that the subject matter is more dedicated to the problem of finding the smallest part per million that can

be reliably identified in the laboratory instead of discussing the deposits of large parts per million which are of practical usefulness and, therefore, of considerable everyday interest.

The immediately succeeding chapters are also written from an academic viewpoint, which is not surprising since the subjects covered are radioactive heat and radiation damage. The first of these is written by Francis Birch and is an excellent summary of the major ideas by this leading student of heat sources in the earth. However, the net effect of the discussion is the conclusion that the large, concentrated attack of recent years on this problem has simply served to reveal its complexity and to define very clearly the major discrepancies in the existing theories on earth-heat. Radiation damage, on the other hand, is concerned with a presentation of the data on crystal distortion created by radioactivity and the possible use of this distortion in such problems as age determination.

The chapter on the effect of radioactivity on the production of hydrocarbons does not introduce any new information. It concludes that such material is formed by radioactivity but that the amounts are small.

The chapter on geophysical exploration, including logging methods, is unsatisfactory because it presents old information of a very general character. This particular reviewer regrets that more quantitative information of the case-history type was not included. Such information does exist and the field has progressed far enough to warrant a very objective appraisal of the various prospecting techniques as evaluated from actual field data. The final 120 pages are devoted to the broad subjects of age determination and the origin of the earth. Again no significantly new material is added but the pages do contribute a well-written and useful compilation of the information that has accumulated on absolute age and of the theories of the earth's origin.

Therefore, it may be concluded that the book is welcome because it compiles much useful information on a new subject. It will be, if it is not already, of direct concern to exploration geophysicists. However, the appearance of the volume does not remove the need for additional publications of more direct applicability as far as exploration is concerned. Such a book will probably be written by one authority instead of by many individuals who are engaged in the academic aspects of the subject. The contributors to *Nuclear Geology* are almost entirely from universities and laboratories, both privately and governmentally supported.

NELSON C. STEENLAND

GEOPHYSICS, VOL. XX, NO. 2 (APRIL, 1955 ),PP. 348-351. 2 FIGS

# MEMORIAL

LOWELL WALLER SAUNDERS

The oil industry, the geologic fraternity, and the community of Bakersfield mourn the tragic loss of Lowell Saunders in an automobile accident June 20, 1954. And the world has lost one of those rare persons whose presence made it a bit better for his being here, even for so short a stay.

Lowell Saunders was born on his parents' ranch west of Red Bluff, California, on September 30, 1901. His early years through to the end of high school were spent here in the rolling hills of the upper Sacramento Valley.

Saunders received a B.S. degree in geology from Stanford in 1922 and im-

mediately headed for the Taft area oil fields and a possible job. He got one in production work with the Ethel D. Oil Company. Thus equipped, he married his boyhood sweetheart, Edna Sells, on December 5, 1923, and soon thereafter took a post with the California Division of Oil and Gas at Taft as petroleum engineer and inspector. Saunders was transferred to Los Angeles and then to Long Beach where he was advanced to deputy supervisor of that district. But his inherent desire to broaden his background led him to go to work at Fellows as geologist, under Ralph D. Reed, for the California Petroleum Company (later taken over by The Texas Company). Here he remained until 1929 when the opportunity arose for him to become district geologist for the Ohio Oil Company in Bakersfield. While with this company, he engaged in some of the pioneer geophysical investigations in the San Joaquin Valley, one of which led to the discovery of the Paloma field. He also was involved in the founding of both United Geophysical Company and Western Geophysical Company. The finding of new fields in the floor of the Valley gave Lowell Saunders a tremendous psychological lift, for the experts were saying, then as now, that the good oil pools had all been found, especially in California. So it is not surprising that Saunders "took off on his own," as he put it, and in 1932 set up shop as a consulting geologist in Bakersfield. In June, 1939, he founded the Independent Exploration Company (now Intex Oil Company) with an integrated staff to handle land, geology, engineering, and production. He was successively vice-president, president, and at the time of his death, chairman of the board.

Saunders was an extremely literate man and his love of reading stemmed from the childhood availability of a good family library. In college, in spite of an eagerness to gain paying control of his specialty, he did not overlook the priceless opportunity to expand his love of literature and history. And his early interest in guns was expressed in later life by a professional approach to the science of ballistics. He developed the Saunders-Krag .22 high-velocity cartridge and helped design and fabricate many of the custom rifles in his collection.

Saunders liked people and was genuinely interested in the welfare of his host of friends. Many sought his advice and he ever gave freely of his time and efforts to give them a lift. Many geologists (and many non-geologists) who chance to read these lines will recall that a talk with Saunders has probably influenced the course of their careers.

Lowell Saunders is survived by his wife, Edna; four children, Edward W. Saunders, Mrs. Diane Lake, Mrs. Doska Wagoner, Miss Susan Saunders; three grandchildren, Carol Lynn Saunders, Lowell William Saunders, Katherine Lake; his mother, Mrs. E. W. Saunders; two sisters, Mrs. Beverly Brown and Miss Hollis Saunders; and a brother, Ellison Saunders.

He was an active member of the American Association of Petroleum Geologists and the Society of Exploration Geophysicists.

V. L. VANDER HOOF

# MEMORIAL

FREDERICK LeVERNE SERVISS

Frederick LeVerne (Fred) Serviss, Professor and Chairman of the Division of Geology of the School of Chemical and Metallurgical Engineering of Purdue University, died unexpectedly and quietly in his sleep on the night of July 22 at his home, 136 East Stadium Avenue, West Lafayette, Indiana.

Fred, the son of Harry L. and Nellie Serviss, was born at Telluride, Colorado, July 30, 1895. His early schooling was in Trinidad and Denver. Later he attended the Colorado School of Mines from which he received an Engineer of Mines Degree in 1920 and an M.S. in Geology in 1922.

After gaining a varied experience as a mining engineer and geologist in the West, both before and after graduation from college, with such firms as the American Metals Company, the Tonopah Placer Mining Company, the Colorado Fuel and Iron Company, and the Utah Fuel Company, Fred entered the teaching profession in 1923 as an instructor at Catholic University of America, Washington, D. C. While in this position, he carried on part-time graduate studies in science and economics at Georgetown University and did consulting work for the firm of Reubsam and Stevens.

Fred transferred to Purdue University in the fall of 1929, where his main fields of interest were mineralogy, economic geology, and engineering geology. Con-

sulting practice on coal for the Pennsylvania Railroad and problems involving the Bedford limestone as a building stone for the Indiana Limestone Company served to broaden his background in applied geology and to lend stimulation to his teaching.

Professor Serviss received recognition from many technical as well as non-technical societies. He held membership or fellowship in the American Institute of Mining and Metallurgical Engineers, the Geological Society of America, the American Association of Petroleum Geologists, the Society of Exploration Geophysicists, the American Society of Civil Engineers, the American Geophysical Union, the American Geographical Society, the New York Academy of Science, the American Association for the Advancement of Science, the American Academy of Political and Social Science, and the Academy of Political Science. He was also honored by election to the following national professional Greek-letter societies: Pi Tau Sigma, Sigma Xi, Tau Beta Pi, Phi Lambda Upsilon, Sigma Gamma Epsilon, and Chi Epsilon. He was advisor to the Catalyst Club and to the Purdue Chapter of Sigma Gamma Epsilon. He was a member of the Kappa Sigma social fraternity, of the Knights of Columbus, and a member of the board of advisors of St. Francis High School, Lafayette. He had been a registered professional engineer in the states of Indiana, Illinois, and Colorado.

He married Abigail McCarthy, December 26, 1920. Mrs. Serviss died February 1, 1941. Their family consisted of ten children of whom the first died in infancy. The following nine survivors are: Donald, Long Beach, California; Daniel, West Lafayette; Elizabeth (Mrs. Bernard Kremer) and Helen (Mrs. Charles Fisher, Jr.), Lafayette; and the following at the West Lafayette home: John, Dorothy, Mary Ellen and Mary Eileen (twins), and Margaret. At the time of Fred's death the youngest survivor was sixteen.

The esteem with which his colleagues on the faculty of Purdue regarded him is brought out in the following statement by a committee of three selected to prepare a memorial resolution:

> Professor Serviss devoted his life to his family and to his profession. Following Mrs. Serviss' death, he had the chief responsibility of bringing up the children. His time and his energies were divided between his family and his geological teaching. The nine splendid children that he leaves, now almost all grown as the youngest is sixteen, are witness to his loving care as father of his family. His teaching at Purdue University was noteworthy. His patience, skill, and interest in seeing that his students obtained a comprehension of geology and mineralogy especially from the economic viewpoint, made him an outstanding teacher not only in his school but in his university. . . . In particular was Professor Serviss skilled in visual aids. Also the laboratories under his direction were extraordinarily neat and orderly. The private scientific library that Professor Serviss accumulated over the years was remarkable—and *more* remarkable was the fact that he found time to read all these books. At heart Fred Serviss was a scholar! In addition to his teaching duties, he devoted many hours to committee and supervisory work for his school and for the university and in particular on the Commencement Committee. His service to the entire university was so skillful and so useful that he will be missed not only by students but by the staff in his own school and the entire university.
>
> F. M. Van Tuyl
> James G. Johnstone

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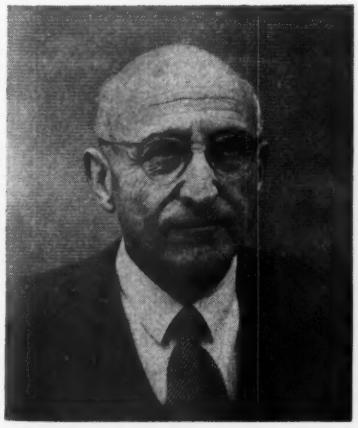
# CONTRIBUTORS

JOHAN F. ENSLIN received a B.Sc. degree in Physics and Chemistry, with additional majors in Mathematics and Geology in 1934, a M.Sc. degree in Physics in 1935, and a D.Sc. degree in 1944 from the University of Stellenbosch, South Africa.

He joined the staff of the Geological Survey of the Union of South Africa as assistant geologist in 1936 and is now senior geophysicist in the Underground Water and Geophysics Branch of that organization.

Dr. Enslin has been elected President of the Geological Society of South Africa for the 1955–1956 term. He is a member of the Suid-Afrikaanse Akademie vir Wetenskap en Kuns, the Royal Society of South Africa, the Society of Exploration Geophysicists, and the American Geophysical Union.

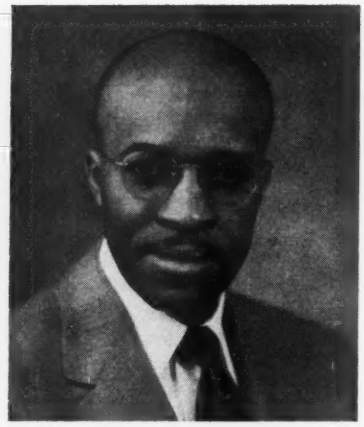
JOHAN F. ENSLIN



BENO GUTENBERG

BENO GUTENBERG received his Ph.D. in geophysics as major, geometry and applied mathematics as minors in 1911 at the University of Göttingen. He was Assistant at the International Seismological central office in Strassburg before the First World War, and later became connected with the University of Frankfurt where he was promoted to Professor Extraordinarius in Geophysics. Since 1930 he has been Professor of Geophysics at the California Institute of Technology, and since 1947 he has been Director of its Seismological Laboratory in Pasadena. His research covers chiefly problems of propagation of elastic waves in the earth and the atmosphere, as well as questions concerning the structure of the earth.

Dr. Gutenberg has been a member of the Society of Exploration Geophysicists since 1936. He has published previously in GEOPHYSICS (vol. 1: "The Amplitudes of Waves To Be Expected in Seismic Prospecting," and vol. 2: "Geophysics as a Science").



ROLAND G. HENDERSON

ROLAND G. HENDERSON received the bachelor's degree with majors in mathematics and physics from the Wisconsin State Teachers College, Milwaukee in 1935. He obtained his M.S. degree in mathematics from Atlanta University in 1939. From 1939 to 1941 he pursued graduate studies in mathematics and physics at the University of Wisconsin, and became a Julius Rosenwald Fellow there, 1940–1941.

He was employed by the Topographic Branch of the U. S. Geological Survey as a geodetic computer, 1942–1946, and as a geodetic engineer, 1946–1947. During this time he did research work in precision altimetry. In 1947 he transferred to the Aeromagnetic Section of the Geophysics Branch of the Survey where he has been engaged in geophysical research.

Mr. Henderson is a member of the national honor fraternity, Kappa Delta Pi; the American Geophysical Union, and the Society of Exploration Geophysicists.

LEONARD VOLK LOMBARDI entered Yale University in 1941 and received a B.S. in Geology in 1946 after serving two years in the United States Marine Corps. He received a M.S. in Geology from Stanford University in 1949, and a Ph.D. in Geophysics in 1953, also from Stanford.

In 1950 he was employed by Stanford Research Institute, eventually becoming head of the Geology and Geophysics Section. He resigned in 1952 to join the exploration department of Gulf Oil Corporation in Fort Worth.

Professional and honorary society affiliations include the Society of Exploration Geophysicists, American Association of Petroleum Geologists, Fort Worth Geological Society, Fort Worth Geophysical Society, Phi Beta Kappa, and Sigma Xi.

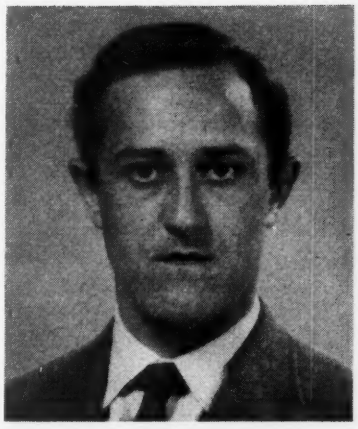
LEONARD VOLK LOMBARDI

LUCIEN MASSÉ

LUCIEN MASSÉ graduated in chemistry from Laval University, Quebec, in 1935. After a few years' work in geophysics in the mining districts of northern Quebec and Ontario, he entered the graduate school at the Colorado School of Mines, obtaining an M.S. in Geology in 1938 and a Sc.D. in Geophysics in 1940. Returning to Quebec, he became Associate Professor of Mathematics, then Professor of Geophysics at Laval University. In 1950, he joined Weiss Geophysical Corporation in New York as Chief Geophysicist and in 1951 moved to Calgary, Alberta, where he became Vice-president of the company. He joined Magnolia Petroleum Company in September, 1954 as Senior Research Physicist. He is a member of the American Mathematical Society.

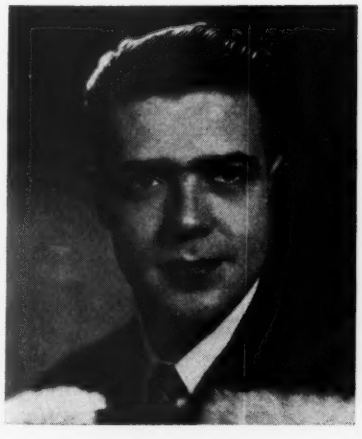
PETER O'BRIEN was born in 1925 in London, England. In 1945 he received the B.Sc. degree in physics from the Imperial College, London, and later that year joined the Shell group as a trainee. After reaching the position of party chief in 1950, he became geophysicist in Scotland with the Ministry of Fuel and Power. He returned to his studies during 1952 and received the M.Sc. in applied geophysics from the University of London. Also in 1952 he became Lecturer in Physics at the University of Toronto, the position he now holds. He received the Ph.D. in Physics from the University of Toronto in 1954.

Dr. O'Brien is a member of the European Association of Exploration Geophysicists and the Society of Exploration Geophysicists.



PETER O'BRIEN

The biography and photograph of CHARLES B. OFFICER, JR., appeared in GEOPHYSICS in v. XVIII, p. 978 (October, 1953) and of C. G. H. OLDHAM in v. XIX, p. 178 (January, 1954).



DON B. SUTHERLAND

DON B. SUTHERLAND received a B.A. degree with Honors in physics and geology in 1953 from the University of Toronto.

While a student he worked during summers obtaining field experience in geophysical methods with McPhar Geophysics and took part in the 1952 GSI-Toronto University student plan.

In the summer of 1953 he conducted a regional gravity survey over an area of the pre-Cambrian shield and as a result of this work was awarded an M.A. in physics in 1954, also from the University of Toronto.

He is presently employed as a senior geophysicist with McPhar Geophysics Limited, and professional affiliations include the Society of Exploration Geophysicists, the European Association of Exploration Geophysicists, and the Canadian Exploration Geophysicists.

ISIDORE ZIETZ

ISIDORE ZIETZ graduated with a B.S. degree in Mathematics in 1939 and a Masters degree in 1940 from the College of the City of New York. He is now fulfilling requirements for the Ph.D. in theoretical physics at the Catholic University of America. He was employed by the U. S. Geological Survey as a field topographic engineer in 1941 and has been working with the Survey since that time. He transferred to the Washington, D. C. office in 1942 as a geodetic engineer and served in the U. S. Army from 1944 to 1946 with the 30th Engineers Base Topographic Battalion doing geodetic and topographic work. Upon discharge from the Army, he returned to the U. S. Geological Survey as a geodetic engineer. In 1946 he transferred to the Geophysics Branch where he has been working for the most part on research in the interpretation of aeromagnetic data. He was a part-time instructor in mathematics from 1946 to 1950 at Catholic University.

Mr. Zietz is a member of Sigma Xi and the Society of Exploration Geophysicists.

# SOCIETY ROUND TABLE

## COMMITTEES

### Executive Committee, Eighteen Months Ending in October, 1955

*President:* Paul L. Lyons, Anchor Petroleum Co., Tulsa, Oklahoma
*Vice-President:* Roy F. Bennett, Sohio Petroleum Co., Oklahoma City, Oklahoma
*Secretary-Treasurer:* Hugh M. Thralls, Consulting Geophysicist, Tulsa, Oklahoma
*Editor:* Milton B. Dobrin, Magnolia Petroleum Co., Dallas, Texas
*Past President:* Roy L. Lay, The Texas Company, New York, N. Y.

### Standing Committee on Nominations

*Chairman:* Paul L. Lyons, Anchor Petroleum Co., Tulsa, Oklahoma

Roy L. Lay — Curtis H. Johnson

### Standing Committee on Program and Arrangements
(New York Meeting)

*Chairman:* Roy F. Bennett, Sohio Petroleum Co., Oklahoma City, Oklahoma

*Program Chairman, New York Meeting:* Ralph B. Ross, Canadian Gulf Oil Co., Calgary, Alberta, Canada

*Arrangements Chairman:* Harvey Cash, The Texas Company, New York, N. Y.

| | | |
|---|---|---|
| B. B. Burroughs | D. W. Ratliff | Milton C. Born |
| Robert B. Baum | A. B. Bryan | R. M. Nugent |
| Don B. Winfrey | W. T. Born | G. A. Berg |
| O. C. Clifford, Jr. | Norman Ricker | Otis B. Hocker |
| Cecil H. Green | Hal R. Adams | John F. Anderson |
| R. W. Dudley | Flint H. Agee | Frank Press |
| W. W. Hardy | W. D. Cortright | Harold O. Seigel |
| M. M. Slotnick | N. Van Der Sleen | John P. Woods |
| Dart Wantland | B. Baars | Bart Pratt |
| O. H. Armstrong | B. H. Treybig, Jr. | |

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*Chairman:* J. B. Macelwane, S.J., Saint Louis University, St. Louis, Missouri

| | | |
|---|---|---|
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| M. King Hubbert | Perry Byerly | Sherwin F. Kelly |
| Beno Gutenberg | | H. W. Straley III |

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*Chairman:* Fred J. Agnich, Geophysical Service Inc., Dallas, Texas

J. Tuzo Wilson — John Hollister — John T. Geer

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*Chairman:* Carl Savit ('55), Western Geophysical Corp., Los Angeles, California

Peter Dehlinger ('55) — Francis F. Campbell ('56) — John Ferguson ('56)

### Standing Committee on Radio Facilities

*Chairman:* R. D. Wyckoff, Gulf Research & Development Co., Pittsburgh, Pa.
*Vice-Chairman:* W. M. Rust, Jr., Humble Oil & Refining Co., Houston, Texas

| | | |
|---|---|---|
| Bart W. Sorge | C. B. Bazzoni | Daniel Silverman |
| E. M. Shook | V. Robert Kerr | Richard Brewer |

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*Chairman:* Bart W. Sorge, United Geophysical Corp., Pasadena, California

T. O. Hall — Francis F. Campbell

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*Chairman:* L. L. Nettleton, Gravity Meter Exploration Co., Houston, Texas ('55)

Andrew Gilmour ('56) — Sigmund Hammer ('58)

George E. Wagoner ('57) — Curtis H. Johnson ('59)

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*Chairman:* John P. Woods, The Atlantic Refining Co., Dallas, Texas

L. L. Nettleton — Cecil H. Green

M. King Hubbert — Sigmund Hammer

### Standing Committee on Reviews

*Chairman:* N. C. Steenland, Gravity Meter Exploration Co., Houston, Texas

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M. M. Slotnick — E. G. Leonardon — T. A. Elkins

W. T. Born

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L. J. Larguier — George D. Gibson — A. A. Hunzicker

Julian Ashby — P. E. Narvarte — G. A. Samuels

John A. Lester — John C. McCaslin — Douglas W. Allan

Sam J. Allen — Richard S. Noble — Kenneth R. Etter

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*Chairman:* R. C. Dunlap, Jr., Geophysical Service Inc., Dallas, Texas

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Stanley W. Wilcox — Van A. Petty, Jr. — Lewis Riley

Philip C. Ingalls

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Herbert Hoover, Jr. — Walter S. Olson — A. Garcia Rojas

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W. H. Newton
Frank Searcy
Bart W. Sorge
John W. Green
G. M. Kintz

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C. Hewitt Dix
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C. H. Hightower
John C. Hollister
R. L. Kisslinger
Lee Park
Frank A. Roberts
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*Editor:* Paul L. Lyons, Anchor Petroleum Co., Tulsa, Oklahoma

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Frank Goldstone
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L. L. Nettleton
Eugene W. Frowe
H. C. McCarver
Roy L. Lay

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*Chairman:* W. M. Rust, Jr., Humble Oil & Refining Co., Houston, Texas

Henry C. Cortes
Cecil H. Green
Andrew Gilmour
Sigmund Hammer
J. J. Jakosky
L. L. Nettleton

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Cecil H. Green
George E. Wagoner

### Special Committee on Standardization of Magnetic Recording of Seismic Signals

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J. E. Hawkins
K. M. Lawrence
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R. A. Peterson
F. A. Van Melle
J. E. White

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*Chairman:* Wm. E. N. Doty, Continental Oil Co., Ponca City, Okla.

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T. J. O'Donnell
L. L. Nettleton
B. D. Lee
H. F. Dunlap
J. M. Crawford
Daniel Silverman

ADVISORY COMMITTEE ON RADIOACTIVE MINERAL EXPLORATION

(Joint committee of AAPG, SEPM, and SEG)

F. H. LAHEE ('55), *Chm.*, Sun Oil Company, Box 2880, Dallas, Texas
HENRY C. CORTES* ('56), *Vice-Chm.*, Magnolia Petroleum Company, Box 900, Dallas, Texas

| 1955 | 1956 | 1957 |
|---|---|---|
| CECIL H. GREEN* | GERHARD HERZOG* | ROLAND F. BEERS* |
| MORTON T. HIGGS | ROBERT R. RIEKE | JEAN C. FINLEY |
| J. HARLAN JOHNSON | WILFRED B. TAPPER | HAROLD N. FISK |
| | GERALD H. WESTBY* | RONALD E. MCADAMS |
| | | H. E. STOMMEL* |

DIRECTORS OF THE AMERICAN GEOLOGICAL INSTITUTE

CURTIS H. JOHNSON (Nov., 1956) SIGMUND HAMMER (Nov., 1955)

REPRESENTATIVE ON DIVISION OF EARTH SCIENCES
NATIONAL RESEARCH COUNCIL

C. B. BAZZONI (June, 1955)

REPRESENTATIVE ON COUNCIL OF
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

ROLAND F. BEERS, Beers and Heroy, Troy, N. Y.

* SEG Members.

## LOCAL SECTIONS

### GEOPHYSICAL SOCIETY OF TULSA

(CHARTERED FEBRUARY 2, 1948)

*President:* L. Y. FAUST, Amerada Petroleum Corp., Box 2040, Tulsa 2, Okla.
*1st Vice-President:* FRANK SEARCY, Continental Oil Co., Drawer 1267, Ponca City, Okla.
*2nd Vice-President:* BEN F. RUMMERFIELD, Century Geophysical Corp., Box 6216, Tulsa 17, Okla.
*Secretary:* T. S. GREEN, Sunray Oil Corp., Box 2039, Tulsa 3, Okla.
*Treasurer:* FIELDING L. MITCHELL, The Carter Oil Co., Box 801, Tulsa 2, Okla.
*Editor:* CHARLES W. OLIPHANT, Oliphant Laboratories, Inc., 1905 National Bank of Tulsa Bldg., Tulsa 3, Okla.
*District Representatives:*
A. B. BRYAN ('55), The Carter Oil Co., Box 801, Tulsa 2, Okla.
W. T. BORN ('56), Geophysical Research Corp., Box 2040, Tulsa 2, Okla.
NORMAN RICKER ('57), The Carter Oil Co., Box 801, Tulsa 2, Okla.
*Meetings:* Monthly, 2nd Thursday, 7:00 P.M., meeting only, University of Tulsa, Room 224, Petroleum Science Hall.

### SOCIETY OF EXPLORATION GEOPHYSICISTS HOUSTON SECTION

(CHARTERED FEBRUARY 14, 1948)

*President:* T. O. HALL, General Geophysical Co., 2514 Gulf Bldg., Houston 2, Texas
*1st Vice-President:* FRED E. ROMBERG, Geophysical Service Inc., 839 Esperson Bldg., Houston 2, Texas
*2nd Vice-President:* A. A. HUNZICKER, Seismic Explorations, Inc., 1007 S. Shepherd, Houston, Texas
*Secretary:* H. W. MCDONNOLD, Keystone Exploration Co., 2813 Westheimer, Houston, Texas
*Treasurer:* W. B. LEE, Gulf Research & Development Co., Drawer 2100, Houston, Texas

*District Representatives:*
O. B. HOCKER, The Texas Co., Box 2332, Houston 1, Texas
G. A. BERG, Berg Geophysical Co., 2122 Welch, Houston, Texas
JOHN F. ANDERSON, Anderson & Cooke, 500 San Jacinto Bldg., Houston, Texas
*Meetings:* Monthly, 1st Monday, Noon luncheon ($1.50), Rice Hotel.

## PACIFIC COAST SECTION

(CHARTERED APRIL 12, 1948)

*President:* JOHN W. MATHEWS, Richfield Oil Co., Box 147, Bakersfield, Calif.
*Vice-President Northern District:* RICHARD W. SHOEMAKER, Ohio Oil Co., Box 193, Bakersfield, Calif.
*Vice-President Southern District:* ELLSWORTH M. CURRY, Shell Oil Co., 1008 W. 6th St., Los Angeles 17, Calif.
*Secretary-Treasurer:* L. I. BROCKWAY, Western Gulf Oil Co., Box 1392, Bakersfield, Calif.
*District Representatives:*
FLINT H. AGEE, United Geophysical Corp., 2227 S. 4th Ave., Arcadia, Calif.
WM. D. CORTRIGHT, Tide Water Associated Oil Co., 2202 Terrace Way, Bakersfield, Calif.
MILTON C. BORN, Amerada Petroleum Corp., 552 Subway Terminal Bldg., Los Angeles, Calif.
*Meetings:* Monthly, 2nd Thursday, Noon luncheon ($2.00), Biltmore Hotel, Los Angeles.

## DALLAS GEOPHYSICAL SOCIETY

(CHARTERED AUGUST 7, 1958)

*President:* R. C. DUNLAP, JR., Geophysical Service Inc., 5900 Lemmon Ave., Dallas 9, Texas
*1st Vice-President:* MARTIN C. KELSEY, Rayflex Exploration Co., 6923 Snider Plaza, Dallas, Texas
*2nd Vice-President:* TOM PRICKETT, The Atlantic Refining Co., Box 2819, Dallas 1, Texas
*Secretary-Treasurer:* JOHN T. GEER, Magnolia Petroleum Co., Box 900, Dallas 1, Texas
*District Representatives:*
O. C. CLIFFORD, JR., The Atlantic Refining Co., Box 2819, Dallas 1, Texas
CECIL H. GREEN, Geophysical Service Inc., 5900 Lemmon Ave., Dallas 9, Texas
J. P. WOODS, The Atlantic Refining Co., Box 2819, Dallas 1, Texas
*Meetings:* Monthly, generally but not invariably 2nd Monday (contact any member). 8:00 P.M. Fondren Science Bldg., S.M.U.

## FORT WORTH GEOPHYSICAL SOCIETY

(CHARTERED AUGUST 7, 1948)

*President:* E. J. GEMMILL, Cities Service Oil Co., 1111 Ft. Worth National Bank Bldg., Fort Worth, Texas
*Vice-President:* H. E. PROKESH, Continental Oil Co., 1710 Fair Bldg., Fort Worth, Texas
*Secretary-Treasurer:* JAMES DIVELBISS, The Chicago Corp., 2122 Continental Life Bldg., Fort Worth, Texas
*District Representative:* R. W. DUDLEY, Kerr-Dudley & Co., 1623 Oil & Gas Bldg., Fort Worth, Texas
*Alternate District Representative:* FRANK O. MORTLOCK, Gulf Oil Corp., Box 1290, Fort Worth, Texas
*Meetings:* Monthly, 4th Monday, Noon luncheon ($1.50), Texas Hotel.

## ARK-LA-TEX GEOPHYSICAL SOCIETY

(CHARTERED MARCH 12, 1949)

*President:* J. RYAN WALKER, Arkansas Fuel Oil Corp., Box 1117, Shreveport, La.
*Vice-President:* GLENN J. BAKER, Wm. M. Barret, Inc., 1431 Dalzell, Shreveport, La.
*Secretary-Treasurer:* BRUCE FOX, The Atlantic Refining Co., 922 Texas Eastern Bldg., Shreveport, La.

*District Representatives:*
B. B. BURROUGHS, Sunray Oil Corp., Ricou-Brewster Bldg., Shreveport, La.
ROBERT B. BAUM, Seismograph Service Corp., 607 Shelby Bldg., Shreveport, La.
*Meetings:* Monthly, last Monday, Noon luncheon ($1.50), Caddo Hotel, Shreveport.

## PERMIAN BASIN GEOPHYSICAL SOCIETY

(CHARTERED JANUARY 30, 1950)

*President:* J. E. FINLEY, Continental Oil Co., Box 431, Midland, Texas
*1st Vice-President:* J. S. PLUTA, Honolulu Oil Corp., Drawer 1391, Midland, Texas
*2nd Vice-President:* R. M. PINSON, Union Oil Co., 619 West Texas, Midland, Texas
*Secretary:* BILLY C. JOHNSON, Forest Oil Corp., Box 2066, Midland, Texas
*Treasurer:* N. R. PARK, Standard Oil Co. of Texas, McClintic Bldg., Midland, Texas
*District Representative:* PAUL C. REED, Forest Oil Corp., Box 2066, Midland, Texas
*Meetings:* Monthly 2nd Tuesday, 7:30 P.M., free coffee and doughnuts, Cowden Jr. High School cafeteria.

## DENVER GEOPHYSICAL SOCIETY

(CHARTERED MAY 19, 1950)

*President:* C. K. SHEPHERD, Continental Oil Co., Continental Oil Bldg., Denver, Colorado
*Vice-President:* E. B. WASSON, The California Co., Box 780, Denver, Colorado
*Secretary-Treasurer:* J. R. REEVES, Aurora Gasoline Co., 227 U. S. National Bank Bldg., Denver, Colorado
*District Representative:* DART WANTLAND, 727 Pearl St., Denver, Colorado
*Meetings:* Monthly, 1st Monday, 5:30 P.M., meeting only, Petroleum Club, 1644 Glenarm Place.

## CANADIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

(CHARTERED JANUARY 24, 1952)

*President:* R. D. HOLLAND, Texaco Exploration Co., 237 7th Ave., Calgary, Alberta
*Vice-President:* E. G. HAINES, Seaboard Oil Co., 630 8th Ave. W., Calgary, Alberta
*Secretary-Treasurer:* H. J. MCGREW, Canadian Gulf Oil Co., Box 130, Calgary, Alberta
*District Representative:* G. F. COOTE, Accurate Exploration Ltd., 2201 10th Ave. W., Calgary, Alberta
*Meetings:* (Data not received)

## GEOPHYSICAL SOCIETY OF OKLAHOMA CITY

(CHARTERED SEPTEMBER 30, 1952)

*President:* FRANK A. ROBERTS, The Carter Oil Co., 1116 Liberty Bank Bldg., Oklahoma City, Okla.
*1st Vice-President:* ARNOLD BLEYBERG, Consultant, 2416 Barclay Rd., Oklahoma City, Okla.
*2nd Vice-President:* J. EUGENE STONES, The Superior Oil Co., 2211 Liberty Bank Bldg., Oklahoma City, Okla.
*Secretary:* JOHN COCHRANE, Jones Shelburne, Inc., 508 NE 26th St., Oklahoma City, Okla.
*Treasurer:* CHARLES E. BECK, Stanolind Oil & Gas Co., Box 1654, Oklahoma City, Okla.
*District Representative:* D. W. RATLIFF, Stanolind Oil & Gas Co., Box 1654, Oklahoma City, Okla.
*Meetings:* Monthly, 2nd or 3rd Monday, 6:30 P.M., Dinner ($1.53), Y.M.C.A., or Y.W.C.A.

## CASPER GEOPHYSICAL SOCIETY

(CHARTERED MAY 23, 1953)

*President:* WENDELL H. HAWKES, Stanolind Oil & Gas Co., Box 40, Casper, Wyoming
*Vice-President:* T. L. MCCORKLE
*Secretary-Treasurer:* J. E. BROOKSHIRE, Box 720, Casper, Wyoming
*District Representative:* DON B. WINFREY, Winfrey Exploration Co., Box 755, Casper, Wyoming
*Meetings:* Monthly, 1st Monday, 7:00 P.M., Dinner ($2.75), Townsend Hotel.

## GEOPHYSICAL SOCIETY OF SOUTH TEXAS

(CHARTERED NOVEMBER 9, 1953)

*President:* JOHN C. COOK, Southwest Research Institute, 8500 Culebra Road, San Antonio 6, Texas
*Vice-President:* WELDON L. CRAWFORD, Petty Geophysical Engineering Co., Box 2061, San Antonio, Texas
*Secretary-Treasurer:* LAWTON B. STEPHENSON, Petty Geophysical Engineering Co., Box 2061, San Antonio, Texas
*District Representative:* BART PRATT, Petty Geophysical Engineering Co., Box 2061, San Antonio, Texas
*Meetings:* Semi-monthly, 2nd and 4th Wednesdays, Noon luncheon (Cafeteria style), Sommers Cafeteria, Main Plaza, San Antonio.

## SOUTHEASTERN GEOPHYSICAL SOCIETY

(CHARTERED APRIL 1, 1954)

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*Vice-President:* J. A. HARRIS, The California Co., 800 The California Co., Bldg., New Orleans 12, La.
*Secretary-Treasurer:* J. B. MEITZEN, Humble Oil & Refg. Co., Box 626, New Orleans 7, La.
*District Representatives:*
CLARK E. ALLEN, Geophysical Service Inc., 522 Arlington Dr., New Orleans 20, La.
K. R. WELLS, General Geophysical Co., 5025 St. Bernard Ave., New Orleans, La.
*Meetings:* Monthly, 3rd Monday, Noon luncheon ($1.50), St. Charles Hotel, New Orleans.

## DAKOTA GEOPHYSICAL SOCIETY

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*2nd Vice-President:* WILLIAM HARLEY, Hercules Powder Co., 1000 14th St., Bismarck, North Dakota
*Secretary-Treasurer:* E. B. COLE, Cities Service Oil Co., Bismarck, North Dakota
*District Representative:* O. H. ARMSTRONG, Mobil Producing Co., Box 1236, Bismarck, North Dakota
*Meetings:* Monthly, 1st Friday, 7:30 P.M., Petroleum Club, Prince Hotel, Bismarck.

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Applications for Active membership have been received from the following candidates. This publication does not constitute an election but places the names before the membership at large, in accordance with Bylaws, Article III, Section 4. If any member has information bearing on the qualifications of these candidates he should send it to the President within thirty days.

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### TECHNICAL PROGRAM FOR SOCIETY OF EXPLORATION GEOPHYSICISTS' NEW YORK MEETING WITH THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS AND SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

HOTEL STATLER, NEW YORK CITY

MARCH 28–30, 1955

*Present Day Frontiers of Oil Exploration.*

L. R. NEWFARMER, Shell Oil Company, Los Angeles, California

Exploration on a frontier, "a border region not fully explored," is more attractive than a gleaning operation in well explored territory, but many true frontiers for the oil explorer are much nearer home than Alaska, the Pacific Northwest, the Great Basin, or even the offshore waters. The facts concerning the stratigraphy and structure of each oil objective must be learned a step at a time from control points; i.e., wells, measured surface sections and datum elevations determined by geophysics. The minimum control point density required will depend upon the size and shape expected for economic accumulations, and the factors of size and shape will be governed by the richness of objectives and the nature of structural deformation, both of which can usually be estimated in advance of detailed exploration. Comparison of control point density now on hand with "*minimum adequate control density*" will afford a useful measure of the degree to which oil exploration has already advanced in any area and will prove that parts of many of the older producing basins are less than fifty percent explored.

*Geophysical Activity in 1954.*

SIGMUND HAMMER, Gulf Research & Development Company, Pittsburgh, Pennsylvania

Statistics on world-wide geophysical exploration activities during calendar year 1954 are reported. The data are classified according to area, method, and cost. All applications are covered, the principal ones being explorations for petroleum and metallic ores. The last half of 1954 shows a significant decline in seismic explorations for petroleum in the United States and Canada. Other geophysical activities were on about the same level or higher than in 1953.

*Interpretation of a Geophysical Prospect.*

R. W. MOSSMAN, Seismograph Service Corporation, Tulsa, Oklahoma

In interpreting geophysical data it is essential to incorporate information on the geologic conditions characteristic of the area of the prospect. An analysis of the data on a purely geophysical basis can lead to very erroneous conclusions. As an illustration, a case history of a seismic prospect in a faulted area is presented, showing successive changes in the interpretation as additional geologic information is introduced into the evaluation. From an economically attractive graben, the interpretation is developed to show that a horst of even greater apparent potential is actually present, which is finally shown to be a very undesirable drilling site.

*Structural and Seismic Deformations along Faults in Eastern Venezuela.*

H. P. LAUBSCHER, Socony-Vacuum Oil Co. of Venezuela, Caracas, Venezuela

Seismic reflections from fault zones in the Eastern Venezuelan basin usually appear distorted. Studies of reflections over fault structures delineated by drilling indicate that this is due to the similar effects of two entirely different phenomena:

1. True structural deformation of beds on the downthrown side.
2. Purely seismic distortion of reflections from underneath the fault.

Analysis indicates that the structural deformation is due to gravitational slump of the downthrown masses because of horizontal tensional movements; the purely seismic distortion is probably caused by passage of the wave front through these slump zones.

These principles are believed applicable in other sedimentary basins.

*Planning a Geophysical Program for an Unexplored Basin.*

T. J. O'DONNELL, Gulf Research & Development Company, Pittsburgh, Pennsylvania

The ideal geophysical program for an unexplored basin would use magnetics, gravity, and seismograph to provide an orderly flow of information leading successively to the determination of the over-all form of the basin and its chief structural elements, to the delimiting of areas worthy of detailed study, and ultimately to the selection of drilling locations. Examples are presented which suggest that these objectives can be obtained most efficiently by planning the program to obtain data of adequate density and precision to permit quantitative interpretation. Geological data and speculation should be made immediately available to the geophysicists so that interpretations can be constantly re-examined in the light of new information and the program modified accordingly.

*Gravity Measurements at Sea, Part II, Southern Part of East Coast of U. S.*

G. LYNN SHURBET,* J. LAMAR WORZEL, and MAURICE EWING, Lamont Geological Observatory, Palisades, New York

Sixty-nine gravity stations at sea were made on four profiles approximately perpendicular to the shore line between Cape Hatteras and the Bahama Islands in U.S.S. MEDREGAL (SS480). Included in these profiles are three detailed crossings from the continental shelf to the Blake Plateau and one detailed section from the Blake Plateau to oceanic depths. Fourteen gravity observations

* Presented paper.

at sea made in U.S.S. ARGONAUT (SS475) provide an additional detailed section from the Blake Plateau to oceanic depths.

Results show that the ocean basin, the Blake Plateau, and the continent are closely in isostatic equilibrium. Five sections computed from reasonable assumptions of the crustal columns of the continent, Blake Plateau, and ocean basin indicate that the mantle rises fairly abruptly beneath the slopes from one province to the next. A more detailed analysis can be made when other information such as seismic refraction data can be obtained.

*Recent Developments in $C^{14}$ Dating.*

J. LAURENCE KULP* and WALLACE R. BROECKER, Lamont Geological Observatory, Palisades, New York

The present status of $C^{14}$ dating techniques will be reviewed. Comparison of sensitivity, precision, age-range and sample size for the solid screen wall counter, gas proportional counters, the liquid scintillation counters and the ionization chamber will be made. It is concluded that the gas proportional counting of carbon dioxide is superior to other methods. Results obtained with these new techniques at the Lamont Observatory will be presented. Advances have been made in the understanding of the modern assay and in the change of sea level during the last 50,000 years. Application to oil geology will be discussed.

*Geomagnetic Measurements in the Gulf of Mexico.*

MAURICE EWING* and EDWARD TITUS MILLER, Lamont Geological Observatory, Palisades, New York

The earth's total magnetic intensity was measured astern the R.V. Vema by a stabilized fluxgate-type magnetometer. Approximately 7500 miles of track form a broad grid over the Gulf of Mexico from which a total intensity map has been prepared.

The magnetic field over the deep basin is unusually uniform. This characteristic extends landward over the continental shelf adjacent to Texas and Louisiana. In contrast to this, the magnetic field over the shelf west of Florida and north of Yucatan is distinctly anomalous. There are numerous anomalies in excess of 100 gammas amplitude with half-widths the order of 3 miles.

The evidence is interpreted as indicating that the igneous basement does not lie as deep beneath the Florida and Yucatan shelves as it does elsewhere in the Gulf of Mexico. Furthermore, the igneous crust under most of the Gulf must have remarkably homogeneous magnetic properties to permit the geomagnetic field to be as uniform as it is.

*Some Unique Features of Seismic Operations on Arctic Ice.*

A. P. CRARY, Air Force Cambridge Research Center, Cambridge, Mass.

Seismic studies by the Air Force Cambridge Research Center have been made on the Arctic pack ice; the ice island, T-3; and along the ice shelf on the northern shores of Ellesmere Island. In many ways the homogeneous ice behaves as a life-size model for seismic wave propagation. Standard, P, S, and Rayleigh waves are illustrated. Various plate waves have also been obtained, including the flexural, air-coupled, and SV reflected waves, all of which give ice thickness data. Cracking in the ice resulting from tidal, wind or thermal stresses set up both compressional and torsional waves, and recordings of these "ice tremors" in three components are discussed. Other features of interest are the triggering of stress tremors by explosive charges and the discovery of bubble pulses resulting from explosive charges in water-filled cylindrical holes in the ice.

*A Structural Analysis of the Major Ranges, Fracture Systems, and Basins of the Cordilleran and Appalachian Systems.*

J. TUZO WILSON, University of Toronto, Toronto, Ontario, Canada

Although the Appalachians and Cordillera are symmetrically placed relative to the continent

* Presented paper.

and have many common features, it has long been recognized that these two mountain systems differ much in the arrangement of their principal features and in their average widths.

Scheidegger has recently published a physical explanation for these differences.

The present paper illustrates how Scheidegger's general theory can be applied to explain specific features of the geology and to predict where other features as yet unrecognized should be sought. In particular the theory leads to a classification of some oil basins with an explanation of some of their characteristics.

*Seismic Operations in Saudi Arabia.*

C. G. FLITTIE, Arabian American Oil Company, New York, New York, and F. J. AGNICH,* Geophysical Service Inc., Dallas, Texas

This is a discussion of seismic operations in Saudi Arabia, with particular emphasis on problems of logistics and equipment requirements for desert operations, illustrated with color slides, and color motion picture of actual operations.

*Geophysical History of Grand Isle, Block 18, Oil Field, Gulf of Mexico, Louisiana.*

LEO A. MARKLEY, Humble Oil & Refining Company, New Orleans, Louisiana

The Grand Isle, Block 18, oil field was discovered in 1948 as a result of gravity and seismograph surveys which indicated the presence of a piercement salt dome. Detailed reflection and refraction surveys were made after the discovery to define more accurately the structure for further development. The shape and extent of the structure as determined from the geophysical data compare favorably with the structural information obtained from the wells drilled to date.

*Geophysical History of the Sharon Ridge Canyon Field, Scurry County, Texas.*

ROBERT C. STONE, Humble Oil & Refining Company, Midland, Texas

The Humble Oil & Refining Company's early geophysical exploration effort in the Sharon Ridge area included a reconnaissance gravity meter survey in 1937 and a reconnaissance reflection survey in 1938. In 1949, following the discovery of the Sharon Ridge Canyon field, a detailed reflection survey was made of the entire southwestern portion of Scurry County. The results of the gravity meter and seismic work are compared with the reef structure that is revealed by present subsurface control.

Conversion of reflection time to depth is accomplished by means of a local velocity gradient map.

*Problems of Uranium Exploration.*

THOMAS R. SHUGART, Research, Inc., Dallas, Texas

The present state of knowledge with regard to the geology of uranium occurrence is briefly outlined. Some of the geological problems of uranium exploration are stated. The application of various geophysical and geochemical techniques to the solution of these geological problems is discussed. A typical exploration program is described in which geology and geophysics are combined to meet present day exploration requirements.

*Simultaneous Gamma Ray and Resistivity Logging as Applied to Uranium Exploration.*

R. A. BRODING* and BEN F. RUMMERFIELD, Century Geophysical Corp., Tulsa, Oklahoma

The transferring of petroleum exploration thinking and methods to uranium exploration has greatly facilitated the search for radioactive ores. The application of radioactive and resistivity logging to locate mineralized zones in shallow core holes obviates the need and expense of taking continuous cores. Instrumentation, field equipment, and techniques are discussed.

* Presented paper.

*The Shallow Reflection Seismograph in Mining, Engineering, and Ground-Water Investigations.*

L. C. PAKISER* AND R. E. WARRICK, U. S. Geological Survey, Washington, D. C. and Denver, Colorado

Following successful tests of a specially constructed shallow-reflection seismograph in early 1954, new experimental work has been conducted on the Colorado Plateau, in the Upper Mississippi Valley zinc-lead district, and in Portage County, Ohio. Although reflections were recorded in all of these areas, they were not continuous and correlatable on the Colorado Plateau and in the Upper Mississippi Valley. In Ohio, on the other hand, reflections were recorded from horizons within the Pleistocene overburden as well as from bedrock and horizons within the consolidated rock section. Conditions favoring good reflections are similar for both shallow- and deep-reflection work; they differ only in scale.

*Application of High Frequency Seismic Techniques.*

K. E. BURG, Geophysical Service Inc., Dallas, Texas

Conventional seismic techniques in the past have used frequencies primarily within the band of 20 to 70 cycles per second. The new H.R. (high resolution) system recently developed for the recording of higher frequency reflections has opened a new field in seismic exploration. The specifications of a recording system designed to record these higher frequency reflections are somewhat different than those suitable for conventional recording. As would be expected, many new problems have been encountered and considerable new knowledge has been added.

The H.R. system is applicable in shallow reflection areas, in areas where higher resolution permits the detection of significant changes in thickness and lithology of the formations, and in areas where the thickness and travel time through low velocity near-surface formations must be determined. The H.R. system is also applicable to various mining overburden and ground water problems.

A number of examples show these various applications.

*Preliminary Report on Total-Intensity Magnetic Interpretations by Means of Model-Field Studies.*

ISIDORE ZIETZ* and ROLAND G. HENDERSON, U. S. Geological Survey, Washington, D. C.

A method is presented for interpreting total-intensity aeromagnetic anomalies of three-dimensional structures. The anomalous structure is approximated by prismatic rectangular slabs of constant thickness and varying horizontal dimensions. The magnetic field for any irregularly shaped magnetic mass may be approximated by superimposing the appropriate contoured maps and adding numerically the effects at each point. The contoured total-intensity fields of these slabs buried at different depths and for several magnetic inclinations will be published later.

*The Limitations of Resistivity Methods of Geophysical Prospecting in Mining Exploration.*

J. EWART BLANCHARD, Nova Scotia Research Foundation, Halifax, Nova Scotia

Resistivity methods are limited by many factors. In order to determine these quantitatively it is helpful to assume ideal conditions of homogeneous overburden, country rock, and ore. With these restrictions approximate expressions are given for calculating the anomalous field to be expected from spherical and cylindrical shaped ore bodies in rock beneath a layer of overburden. Various electrode configurations are discussed. Numerical values are given for several situations of practical importance.

*Results of Airborne Radioactive, Electromagnetic, and Magnetic Surveys.*

HANS LUNDBERG, Hans Lundberg Ltd., Toronto, Ontario, Canada

Airborne recording of radiation from the earth's surface is a new method of geological mapping.

* Presented paper.

After eliminating effects from topography, surface waters, and known geology, a pattern often remains that may enable the geologist (geophysicist) to outline direct indications of oil and gas accumulations which apparently have a blocking effect upon upward trending movements. The position of radioactive mineral deposits may also be revealed directly in detail surveys, and it is also possible to distinguish the effect of uranium from that of thorium and potassium.

In sedimentary regions airborne electromagnetic surveys may reveal underlying structures down to 1,000 or 2,000 feet by recording the effects of secondary fields created in good conducting layers by a transmitter in the plane. In order to outline deposits of conductive bodies of mineralization, current is supplied to the ground by means of very long cables with enough effect to directly outline the conducting bodies at depth from airborne recordings.

Airborne recording of the total magnetic field over very large areas greatly assists geological mapping. For detail studies the recording of the vertical component at low altitude is found to be an excellent method of outlining magnetic orebodies and zones of mineralization, particularly in the pre-Cambrian formations.

*Acoustic Logging and Its Geophysical and Geological Applications.*

H. R. Breck, S. W. Schoellhorn, and R. B. Baum,* Seismograph Service Corp., Tulsa, Oklahoma

Acoustic logging, as a general service to the oil industry, is less than a year old. Even with this short period of experience, a number of observations can be made which indicate that the acoustic log will make some valuable contributions to the total of information obtainable from a drilled hole.

The most obvious application of the acoustic log is the replacement of the conventional velocity survey. Data obtained are comprehensive and accurate. Whenever the industry is convinced of the truth of the foregoing statement, a material reduction in cost of velocity surveys will be possible.

From the standpoint of the geologist, the acoustic log provides another correlation medium. The log is derived from a heretofore unmeasured physical property and hence emphasizes variations not measured by other logs. A qualitative correlation of relative porosity with some velocity changes seems obvious. If this part of the service can be refined to present quantitative figures, it will be the major contribution to oil prospectors.

*Elastic Wave Velocities in Heterogeneous and Porous Media.*

M. R. J. Wyllie,* A. R. Gregory, and L. W. Gardner, Gulf Research & Development Company, Pittsburgh, Pennsylvania

Longitudinal wave velocities in numerous synthetic and natural porous media at room temperature and pressure have been measured. Basic characteristics of the measuring device are briefly described. Wave velocities have been found for aggregates of uniform spheres of various diameters both when dry and when saturated with water, brine, carbon tetrachloride and plastics. The effect of porosity on the wave velocity through aggregates of glass spheres saturated with plastic has been determined over the porosity range 19–70 percent. Experimental measurements have been made of the effect of varying brine-oil and brine-gas saturations on the wave velocity through natural sedimentary rock samples. The effect of salinity and temperature on the wave velocity through sodium chloride brines has been redetermined.

Results are graphically presented to show experimental relationships between wave velocity, porosity, pore content, and matrix nature of sedimentary rocks. Some conclusions are drawn regarding general relationships between these factors based on the experimental results and on theoretical considerations. Through these relationships continuous velocity logs can be interpreted to furnish a measure of formation porosity. Some comparisons are given between porosities derived from continuous velocity logs and found by core analysis.

* Presented paper.

*Seismic Wave Propagation in Porous Granular Media.*

NORMAN R. PATERSON, University of Toronto, Toronto, Ontario, Canada

Theoretical and experimental studies have been made of the manner in which sound waves are propagated in porous granular aggregates. Use is made of a radiating piezo-electric cylinder in order to simulate the explosion of a charge in a seismic shot hole.

It is found that in packings of un-cemented spherical grains the sound velocity is related to the stress in the frame and to the elastic constants of the grains and pore-filling material. Density and porosity are additional parameters in the dry system, while viscosity and permeability are important in liquid-filled aggregates.

The additional effects of lithification and texture have been studied and some conclusions drawn.

*The Long Interval Method of Measuring Seismic Velocity.*

F. P. KOKESH, Schlumberger Well Surveying Corporation, Houston, Texas

The method of seismic velocity determination, wherein the shot is detonated in a borehole and the energy is detected at the surface, has been extended to operate in deep holes. This has been accomplished by the use of a long interval arrangement of a multi-shot selective firing sound source gun and one or more geophones separated vertically by a cable several hundred feet long. A series of a relatively few such intervals can "strap" a hole travel time-wise with good accuracy. The high-frequency content of energy generated by shooting in deep holes permits first arrival determinations to a fraction of a millisecond. The accuracy of the interval measurements can be verified by overlapping intervals. Travel time measurements over the cased portion of the hole can generally be accomplished by means of geophones placed at the surface. Operations are confined mainly to the boreholes, eliminating the need for numerous shot holes and handling of dynamite charges. Velocity surveys conducted in this manner become a routine well logging service, conducted in conjunction with other services, such as electrical logs. Comparisons with conventional geophone surveys show that the long interval method has the advantages of substantial savings in cost, increased convenience, and more reliable results. The paper describes, in a general way, the necessary field equipment; and field examples of surveys are presented.

*The Effect of Topography on Near-Surface Velocities.*

WILFRED BAILLIE, Frontier Geophysical Ltd., Calgary, Alberta, Canada

Fictitious seismic anomalies often result from the use of improper velocities in making the elevation correction in seismic interpretation. The frequent coincidence of apparent seismic highs with topographic highs indicates a possible relationship between surface load and velocity. The importance of the load-factor is illustrated by an actual example in which a series of core hole velocity measurements were made over an apparent anomaly.

*The Treatment of Lateral Velocity Variation in Seismic Interpretation.*

LOUIS W. GARDNER, Gulf Research & Development Company, Pittsburgh, Pennsylvania

Lateral velocity variations are associated with geologic structural, stratigraphic, and lithologic conditions. The construction of the most suitable time-depth conversion chart applicable to a given area for seismic interpretation depends upon these conditions. A number of different cases are treated which typify sets of conditions present in different areas and basins.

Regional velocity corrections are necessary to account for facies change but may incorporate other factors either deliberately or inadvertently. Some comments are made with respect to subweathering velocity variation, reef influence, influence of overthrustings and topographic corrections. There is interdependence between the several different kinds of velocity corrections and the time-depth chart which becomes increasingly binding with increase in amount of available vertical velocity

* Presented paper.

information. Consequently, there is a pitfall that a poor assignment of one factor can induce a poor assignment of a second factor with deleterious effect upon mapped results.

*The Application of a Three Component Model to the S.P. and Resistivity Phenomena Evinced by Dirty Sands.*

P. F. SOUTHWICK,* K. S. SPIEGLER, and M. R. J. WYLLIE, Gulf Research & Development Company, Pittsburgh, Pennsylvania

A simple resistor model consisting of three components in parallel and representing (a) a component made up of the conductances of solution and conducting solid particles in series; (b) a component made up of the conductance of the solid particles only, and (c) a component made up of solution conductance only, has been found to explain satisfactorily the experimental relationship of the conductivities of solutions used to saturate synthetic dirty sands and the conductivities of the saturated sands. The synthetic dirty sands consisted of beds of ion-exchange particles.

The same model is applied to give a theoretical explanation of the potentials which arise between two different solutions when these meet in the interstices of a synthetic dirty sand; excellent agreement between theory and experiment is observed. The theory is extended to cover the case of an oil-bearing synthetic dirty sand and the relationship between oil saturation and apparent resistivity index calculated by the conventional methods used in logging interpretation. On the assumption that synthetic dirty sands are electrochemically equivalent to natural dirty sands, the results are used to show the conditions necessary for the satisfactory interpretation of productive dirty sands from electric logs.

*A New Seismic Technique and Results to Date.*

R. L. PALMER, McCollum Exploration Company, Houston, Texas

This technique comprises utilization of seismic energy from a large weight dropping at closely spaced intervals, correcting the time of reflected events for step-out and elevation, and integrating the corrected individual drops to give a composite seismogram that attenuates the horizontal and low angle event and accentuates the time corrected reflected event. A resume of the results of the technique to date as shown by subsequent drilling. Paper illustrated by short movie and slides.

*Seismic Model Studies.*

JACK OLIVER, FRANK PRESS,* and MAURICE EWING, Lamont Geological Observatory, Palisades, New York

The seismic model technique, described in previous papers, has been applied to several new problems. One concerns the propagation of elastic waves in a medium in which the velocity varies continuously with depth. In such a configuration wave paths may become tangential to a horizontal discontinuity in which case boundary waves diffracted along the discontinuity are excited.

Similar waves may be excited in isotropic media when an incident $S$ wave strikes a discontinuity at the critical angle. These waves have not to the authors' knowledge been observed previously at the boundary between two different materials.

The effect of curvature of the surface on waves of the Rayleigh type has been also investigated experimentally. The dispersion is in good agreement with the theoretical results of Sezawa for Rayleigh waves travelling around a cylinder.

*A New Method of Interpretation of Aeromagnetic Maps: Pseudo-Gravimetric Anomalies.*

V. BARANOV, Compagnie Générale de Géophysique, Paris, France

The purpose of this paper is to describe a method of interpretation based on a transformation of the total magnetic intensity anomalies into more simple anomalies. The result of this transformation

* Presented paper.

is the elimination of the distortion due to the obliquity of the normal magnetic field, so that the resulting anomalies will be located on the vertical of the disturbing magnetized bodies.

The starting point of the theory is the well known relation between magnetic potential $V$ and Newtonian potential $U$, a relation which can be written

$$\vec{\tau} \cdot \overrightarrow{\text{grad}}\, U = f\sigma \cdot V$$

with

$\vec{\tau}$ = magnetization

$f = 66,7 \cdot 10^{-9} uCGS$

$\sigma$ = assumed density of magnetized bodies.

This relation may be considered as a partial differential equation. The boundary condition consists in the measured values of the total field $T(P)$ known at each point $P$ of the datum plane. As $T(P)$ is the derivative of a harmonic function $V$, we can determine this function everywhere above the datum plane. Solving then the partial differential equation, we find the Newtonian potential $U$ and its vertical derivatives $g, g', g'', \ldots$

Finally, we obtain these quantities as functionals of the measured magnetic anomaly $T(P)$. For instance, one of the formulae is

$$g(M) = \frac{1}{2\pi} \int\int H(M, P) T(P) dS_P$$

where $H(M, P)$ is the kernel of the transformation allowing the direct computation of $g(M)$,—an anomalous field which will be called "pseudo-gravimetric anomaly."

Of course, the pseudo-gravimetric anomaly has all the usual properties of a gravimetric anomaly. The field of $g(M)$ presents no distortion and the interpretation becomes as easy as that of a Bouguer anomaly map.

To perform the actual routine calculations of this transformation, we start with the values of $T$ taken on a rectangular or trigonal grid, as for the usual computation of the vertical derivatives. The use of punched-card equipment speeds up considerably these calculations.

*Seismic Wave Attenuation Characteristics from Pulse Experiments.*

F. A. Collins* and C. C. Lee, The Atlantic Refining Company, Dallas, Texas

Stress wave attenuation characteristics can be expressed by a stress-strain relation, which can be combined in a well-known manner with the strain-displacement relation and Newton's second law to deduce a wave equation applicable in an imperfectly elastic earth. A review of published data indicates that a stress-strain relation in which stress is a linear combination of strain and rates of change of strain is probably not adequate for all earth materials. It appears necessary to express the time-dependent properties of the material by using a memory function, which is incorporated in the stress-strain relation through a convolution integral. A method of obtaining the corresponding integro-differential wave equation by analyzing seismic pulses recorded at several distances from a shot point is described, and applied to data obtained in a quarry sandstone. Although data from this experiment did not yield consistent results for different transmission distances, it is believed that data from additional experiments of this sort can be used to determine the wave propagation equation.

*The Reynolds Plotter.*

Vining T. Reynolds, V. T. Reynolds, Inc., Houston, Texas, and Paul Farren,* National Geophysical Company, Inc., Houston, Texas

A system of seismic data analysis is presented which mechanically identifies, times, computes, and plots in cross-section form (point plot) or record section form (full envelope of each trace) all events on a seismogram.

* Presented paper.

Velocity depth function, and normal move-out, weathering and elevation corrections, are applied to each trace individually as all traces are scanned and reproduced simultaneously by a mechanical process.

The system produces cross-sections and record sections with speed, thoroughness and accuracy. Convenience in correlation of the sections expands the output of the interpreter; flexibility in handling the mass of data facilitates special projects such as velocity, isopach, and magnetic tape studies; thoroughness of presentation of seismic evidence, especially segmental reflections, permit a more valid interpretation.

*Seismic Applications of Some New Filtering Techniques.*

HAL J. JONES, Texas Instruments Incorporated, Dallas, Texas

Modern communications theory and information theory have placed considerable emphasis upon the problem of detection and extraction of signals in noise backgrounds. Some of the methods and equipment developed have possible seismic applications. This paper presents a discussion of the delay-line method of filtering. Magnetic delay-line equipment which permits approximation of a wide variety of linear filters is described in detail. The fundamental theory of delay-line filtering is outlined briefly. Use of non-linear decision-making filters in seismic recording is discussed both from the standpoint of theory and of suitable equipment. The possibility of incorporating these types of filtering equipment in an automatic or semi-automatic seismic data processing system is outlined.

*The Moveout Filter.*

CARL H. SAVIT,* JOHN T. BRUSTAD, and JOSEPH SIDER, Western Geophysical Company, Los Angeles, California

The response of a seismometer array or "pattern" is a function of the wave length (also of the moveout or phase velocity) of incident energy. Patterns are thus "moveout filters." Analyses of pattern behavior in the literature has been confined to the calculation of the response characteristics of specific types of arrays. The present paper develops the general theory of arrays and gives an explicit solution for the design of an array having a predetermined moveout response.

It is further shown that the antenna theory approach to pattern design is inadequate in the seismic case by reason of the non-uniqueness of the velocity of incident energy.

An example of a pattern designed to meet specific requirements is exhibited. The case presented effects a calculated improvement of at least four to one in signal to noise ratio over conventional patterns. The output of the designed system for a horizontally traveling, transient pulse input is shown to be greatly reduced in peak amplitude.

Results of preliminary field tests are in good agreement with theory.

*The Composition of Reflections.*

J. P. WOODS, The Atlantic Refining Company, Dallas, Texas

The reflections seen on a seismic record is often a composite of several reflections. The interpreter thinks that he deals with a single interface, when in reality, he is dealing with a number of close-spaced reflecting layers. If the arrangement of these layers changes, the composite reflection seen on the record will change in time of occurrence and in character. In consequence, the horizon carried by the interpreter will be in error. To demonstrate this composition of reflections, a simple acoustical model has been built and various records made with this model will be shown.

## TWENTY-FIFTH ANNUAL MEETING
## SOCIETY OF EXPLORATION GEOPHYSICISTS

The Twenty-Fifth Anniversary Meeting of the Society of Exploration Geophysicists will be held in the Shirley Savoy Hotel, Denver, Colorado, October 3, 4, 5, and 6, 1955. Members desiring to

present papers at this meeting are requested to submit abstracts before July 15, 1955 to the Program Chairman, MARVIN ROMBERG, The Carter Oil Company, Box 120, Denver, Colorado.

With the objective of providing " . . . a program of the highest type technical papers of interest to all people in mineral exploration," the Denver Geophysical Society and General Chairman ROBERT DYK of Geophysical Service Inc. are now at work on arrangements for the convention. The Planning Committee, under the General Chairman, includes RALPH HOLMER, Bear Creek Mining Co., Vice-Chairman; CHARLES C. O'BOYLE, of Brainard and Van Tuyl, Arrangements Chairman; C. K. SHEPHERD, Continental Oil Co., President of the Denver Section; MARVIN ROMBERG, Program Chairman; and JOHN HOLLISTER, Colorado School of Mines, Advisor. Other committee chairmen are: L. C. BARKER, E. I. duPont de Nemours & Co., Entertainment; LESLIE SPENCER, Tower Exploration, Inc., Housing; L. F. LOCKARD, Sinclair Oil & Gas Co., Publicity; SAM ALLEN, United Geophysical Corp., Registration and Reception; W. M. ERDAHL, Skelly Oil Co., Tulsa, Oklahoma, Exhibits; and C. E. RIDDELL, British American Oil Producing Co., Finance.

Upon announcing appointment of committees Mr. Dyk said "As this is the first convention of the SEG 'on its own,' it is vital that all phases of the meeting be of the highest quality. This meeting will set precedents and standards for future conventions. In reality, a true program committee consists of *all* members of the SEG."

The technical program will include sessions of interest to both geologists and geophysicists, with special emphasis on cooperation between the two earth sciences. Present plans provide for a limit of five papers per session, allowing ample time for discussion; there will be no concurrent sessions. Provision has been made for indoor and outdoor exhibits of commercial and technical companies serving the geophysical industry. Requests for exhibit space should be directed to the Society of Exploration Geophysicists, 624 South Cheyenne, Tulsa, Oklahoma.

## GULF COAST REGIONAL MEETING

### PLAZA HOTEL, SAN ANTONIO, TEXAS

### MAY 19–20, 1955

The Tenth Annual Gulf Coast Meeting of the Society of Exploration Geophysicists will be held May 19 and 20 this year in the Plaza Hotel, San Antonio, Texas. The first nine Gulf Coast meetings were sponsored by members of the SEG Houston Section, who will be joined this year by the Southeastern Geophysical Society of New Orleans and the Geophysical Society of South Texas, San Antonio, as joint sponsors. The San Antonio members will serve as hosts, and will provide the chairmen of most of the committees.

General Chairman is P. E. Narvarte, consulting geophysicist of San Antonio, who is assisted by W. L. Crawford, Petty Geophysical Engineering Co., General Co-chairman. Other committees and their respective chairmen are as follows:

*Housing:* W. R. Gray, Monterrey Exploration Co., San Antonio
*Finance:* W. B. Lee, Gulf Oil Corporation, Houston
*Entertainment:* Van A. Petty, Jr., Petty Geophysical Engineering Co., San Antonio
*Program Publication:* M. G. Frey, The California Company, New Orleans
*Program:* J. O. Parr, Petty Geophysical Engineering Co., San Antonio
*Registration:* John C. Cook, Southwest Research Institute, San Antonio
*Arrangements:* A. F. Hasbrook, Petty Geophysical Engineering Co., San Antonio
*Publicity:* Thos. S. West, West & Gill, Consultants, San Antonio

## INTERNATIONAL ARID LANDS MEETINGS, ALBUQUERQUE AND SOCORRO, NEW MEXICO, APRIL 26–MAY 4, 1955

A symposium and conference on the subject: "What is the Future of Arid Lands?" will be held in Albuquerque and Socorro, New Mexico from April 26 to May 4. These meetings are to be sponsored by the American Association for the Advancement of Science and will be supported by the National Science Foundation, the Rockefeller Foundation, and UNESCO.

The symposium and associated discussion group meetings will be held on the campus of the University of New Mexico, in Albuquerque, from April 26 to April 29. The symposium will consist of three evening lectures open to the public and four half-day technical sessions. Subjects for the respective sessions are: "Variability and Predictability of Water Supply in Arid Regions," "Better Use of Technical Resources," "Prospects for Additional Water Sources," and "Better Adaptation of Plants and Animals to Arid Conditions."

The conference, which takes place from May 2 to May 4 at the New Mexico Institute of Mining and Technology in Socorro, will be attended by members of the UNESCO Advisory Committee on Arid Zone Research, the national and local planning committees, the chairmen and speakers from the symposium sessions, and a small number of invited foreign and U.S. delegates.

A field trip will be conducted for visitors to the meetings on April 30 and May 1. The route is from Albuquerque to White Sands to El Paso, and back to Albuquerque via Elphant Butte Dam.

Papers from the symposium are to be published in book form by the AAAS Further information on the program may be obtained by writing the AAAS at 1515 Massachusetts Avenue, N.W., Washington 5, D. C.

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## COMMITTEE REPORTS

### EXTRACTS FROM THE MINUTES OF THE FIFTH MEETING OF THE ADVISORY COMMITTEE ON RADIOACTIVE MINERAL EXPLORATION AT DALLAS, TEXAS, ON NOVEMBER 15, 1954

. . .

D. The Chairman reported that our informational circulars are being received with much satisfaction by those to whom they have been sent. In May, at the time of our last meeting, there were 50 on our mailing list. At present, there are 105.

These circulars, it will be remembered, are built up largely from useful information which is presented to us at our meetings. They are prepared by the Chairman and, before completion, are always carefully checked and corrected by several members of the committee, and also by one or more members of the Atomic Energy Commission for statements pertaining to that commission. So far we have issued five of these circulars.

. . .

E. To give the members an idea of the nature of many of the requests which come in to the Chairman, he quoted from a recent letter as follows:

"We would like to determine which oil or natural gas companies are leasing or otherwise being permitted to explore for and develop oil, natural gas and/or radioactive minerals on Government properties (with extent of such company interest) in any of the following areas—

1. Utah: the Uintah Basin
2. Wyoming: Powder River Basin, Big Horn Basin, Green River Basin, and the Washakie Basin
3. Arizona: the Little Colorado River drainage area
4. California: Mojave Desert and Colorado Desert."

Of course our committee has practically none of this kind of information. In most cases of this kind, the Chairman refers the correspondent to the Atomic Energy Commission for whatever advice they can furnish.

. . .

G. Concerning the present status of exploring for uranium ores by oil companies, we have the following data which were kindly furnished by the Atomic Energy Commission upon request from the Chairman, who asked (1) how many seismic shot-holes, if any, had been damaged or lost as a result of

probing, (2) in how many such holes probes had been lost, and (3) how many oil companies have been probing their seismic shot-holes for radioactive ores:

From the Salt Lake City office of the A.E.C.:

"The Salt Lake Exploration Branch program of gamma-logging of seismic shot holes by Atomic Energy Commission personnel has been conducted without any mishaps or failures, such as lost probes, damaged holes, or any lost time. It is the practice of this Branch to probe the holes during the time lapse between drilling operations and loading, which in the majority of cases approaches 24 hours. In such cases where caving conditions exist in the hole and pre-loading is done directly after drilling, no probing is attempted.

"A breakdown by states of oil companies engaged in this program is as follows:

*Montana*—Five major companies and one minor company are scanning shot-hole cuttings with A.E.C. equipment.

*Wyoming*—Seven major and four minor or independent companies are allowing A.E.C. personnel to probe shot-holes.

*Utah*—One major company has granted permission to have A.E.C. probe shot-holes.

*Nevada*—Four majors have granted permission for A.E.C. probing.

"Several companies are probing or scanning shot-hole cuttings with instruments and equipment furnished by the Atomic Energy Commission and are forwarding monthly reports of findings and general location of shot lines to the A.E.C.

"Radiometric investigation of shot-holes is being carried out privately by some of the companies throughout our area and it is hoped this practice will be incorporated in more oil companies' geophysical programs. Interest in conducting private surveys of shot holes appears to be increasing."

From the Grand Junction office of the A.E.C.:

"No holes have been damaged, to our knowledge, by probing operations. The time required to carry out the actual probing is relatively short, and no complaints have been received from participating companies in this respect.

"Since the commencement of a seismic shot-hole logging program by the Atomic Energy Commission two years ago the Grand Junction Operations Office has probed 2,352 shot holes for a total depth of 361,122 feet through the courtesy of oil companies doing exploration in the Colorado Plateau area. Our office has been utilizing ten hand-operated Geiger probes and three men to follow field seismic crews. The remaining seven instruments have been placed on loan to various oil companies for hole-probing purposes. Forty-three holes have been found to contain anomalous radioactivity. The information obtained has been forwarded to our office for evaluation, and promptly turned over to the proper oil company.

"To date, 15 major and 4 minor companies have used Atomic Energy Commission probes in conjunction with their seismic programs. Three major companies have inaugurated gamma logging in favorable areas and two more have expressed interest in this type of work.

"The aim in this work has been toward creating interest among the oil companies, and of giving them technical assistance where possible. We appreciate very much the cooperation which they have given us."

It is significant that these probing operations in shot-holes are accomplished so quickly that they occasion no loss of time in the seismic exploration procedure. However, to be this efficient, the man with the probe must be on the ground and ready to run his instrument immediately when the hole is available. Such probing can be done by an employee of the oil company, or by an employee of a contract geophysical company, or by an employee of the Atomic Energy Commission. The A.E.C. is carrying on this probing without cost to the companies soliciting such work, for they (the A.E.C.) are trying to interest and encourage the oil companies to cooperate in exploring for uranium. The A.E.C. would be pleased, however, if the companies would decide to undertake this exploratory work on their own account.

Under heading "G"—present status of exploring for uranium—there was long discussion, the principal items of which may be summed up as follows:

1. The most important requirement for efficient down-the-hole probes is dependability. To date considerable trouble has been experienced by different probes because of failure in one way or another. For example, the cables used must be made proof against leakage, and various mechanical difficulties must be corrected. Probably use of a probe two inches, or nearly two inches, in diameter would help in correcting circuitry problems which are exaggerated by smaller diameters, such as the one-inch, or approximately one-inch, models now frequently used. And, as pointed out at our May meeting, a two-inch diameter should cause no trouble in running into shot-holes.

2. The belief was expressed by several that, if uranium exploration of shot-holes is worth doing, it is worth doing well, and therefore a *dependable* instrument costing $1,500 or $2,000 would, in the long run, be cheaper and more satisfactory than a probe costing, let us say, from $350 to $500. This has been the experience of several of the oil companies.

3. It was also stated that a recording device should be used in conjunction with the probe, so that not only would reliance on personal say-so be unnecessary but also the record could be kept for future reference. It was said that for the smaller probes a recording device would add $250 to $300 to the cost of the simple probe. Preference was indicated for a round chart recorder instead of a strip recorder.

4. Apparently there are many companies and laboratories manufacturing probes, each according to its own ideas and experiences. Several of the oil companies are making their own instruments. It was suggested that if users of these probes could reach agreement on the specifications required, instrument companies would no doubt be encouraged to manufacture standard patterns and sizes for sale to the industry, and probably with considerable saving of time and cost to all concerned. Such standardization would create a demand which would justify manufacture by the instrument companies.

5. Several members stressed the importance of preserving records in the form of logs of the holes surveyed. One member was emphatic in urging an extensive program of logging and mapping the indications of radioactive ores. It was suggested that such a program might be sponsored as a Government project.

H. In the Minutes of our meeting of May 20, 1954, we read: "On May 19, a newspaper report stated that 'The House Interior Committee starts two days of hearing (on May 20) on a bill that would let uranium hunters prospect on public land already reserved for petroleum, gas, and shale prospecting'."

On August 13, 1954, Public Law 585, known as the "Multiple Use Law " was approved. According to this law the right may be granted by the Government on Federal lands separately to explore for and develop oil and/or gas, on the one hand, and radioactive (uranium) ores, on the other hand, under the same tracts, and these rights may be assigned to the same lessee (when separately and properly applied for) or to different lessees. In other words, a lease assigned for petroleum exploration does not *per se* include rights for uranium exploration; and vice versa. Application for each must be made independently of the other.

There followed some discussion of the mineral coverage under regular oil-and-gas leases on fee lands. Generally speaking, some lawyers believe that in these leases "and other minerals" properly would include uranium and any other radioactive ores. The fact that when such leases were drawn up uranium ore was not considered should carry little weight since also, at that time, other more common minerals or ores, such as iron ore, coal, etc., might not have been thought to exist under the land leased nor for many miles around. However, it was pointed out that there have been no court decisions on this question as yet.

On the assumption that an oil-and-gas lease on fee land *does* include "other minerals," and therefore uranium ore, the lawyers agree that the lessee therefore has the right to trade any or all of his $\frac{7}{8}$ interest (or other designated portion) in these other minerals to any purchaser, always, of course, with the understanding that the Government's regulations pertaining to radioactive ores *must* be obeyed by the owner of the lease on these ores. Presumably these regulations would also apply to the owner of the $\frac{7}{8}$ as protector of the farmer's rights in the additional $\frac{1}{8}$.

I. Mention was made of several publications which may be of interest to the members. These were:

(1) "Nuclear Processes in Geologic Settings," a small summary of discussions by eminent workers on nuclear physics, published by the University of Chicago Press. This probably has very little bearing on the particular objectives of this committee.

(2) The October issue of "The Mines Magazine," of the Colorado School of Mines, in which these articles appeared:
   (a) "The Outlook for Uranium Mining," by Jesse C. Johnson.
   (b) "Status of the Domestic Uranium Production Program," by Sheldon P. Wimpfen.
   (c) "Drilling Techniques of the Colorado Plateau," by R. G. Sullivan.
   (d) "Problems of Private Industry's Future in Uranium Exploration and Development," by G. R. Kennedy.
   (e) "Airborne Exploration for Uranium," by Royal S. Foote.

(3) "Uranium," a small periodical published monthly at 601 Odgen Street, Denver, Colorado. The September issue was No. 2 in Volume one of this journal.

(4) "The New Atomic Energy Law: What it Means to Industry," published by the Atomic Industrial Forum, 260 Madison Avenue, New York 16, and due very shortly.

(5) "Bibliography and Index of Literature on Uranium and Thorium and Radioactive Occurrences in the United States," published in 3 parts in the Bulletin of the Geological Society of America, as follows:
   Part 1.—Arizona, Nevada, and New Mexico
   Bulletin Volume 64, Pages 197–234. February 1953
   Part 2.—California, Indiana, Montana, Oregon, Washington, and Wyoming
   Bulletin Volume 64, Pages 1103–1172. October 1953
   Part 3.—Colorado and Utah
   Bulletin Volume 65, Pages 467–590. June 1954

(6) "Minerals for Atomic Energy," by Robert D. Nininger, published by Van Nostrand Company.

FREDERIC H. LAHEE, *Chairman*
November 23, 1954

## S.E.G. COMMITTEE ON STANDARDIZATION OF MAGNETIC RECORDING OF SEISMIC SIGNALS

### MINUTES OF MEETING

### NOVEMBER 18, 1954

The second meeting of the S.E.G. Committee on Standardization of Magnetic Recording of Seismic Signals was held in Dallas, Texas, on Thursday, November 18, 1954, at 5:00 P.M., in Parlor F on the mezzanine floor of the Adolphus Hotel.

Mr. Thompson, chairman of the committee, explained the status to date of the work of the committee and developments since the last meeting, including the report of the Sub-committee on Definitions and Measurement Procedures. He then reviewed the list of subjects for consideration suggested by the sub-committee.

Mr. Doty, chairman of the sub-committee, commented on the excellent attitude of his group toward their assignment. He expects no controversial difficulties to develop. They will borrow from I.R.E. and motion picture standards. One of the main problems will be deciding which of various factors to include in defining signal-to-noise ratio. The sub-committee would like to publish its proposals inviting comments before final standards are settled.

It was explained with regard to the work of the sub-committee that no time limit had been set as to when final standards would be established. The work should not proceed too fast or it might not receive general acceptance by the industry. The suggestion that six months might be sufficient was contested by Mr. Begun, who felt that two years would be a better estimate considering the problems

encountered by the other committees attempting standardizations. It was generally agreed that some gain would result if tentative proposals on some topics were published very soon, by-passing more difficult topics temporarily. These tentative proposals, in the form of a "progress report," should be ready and circulated two or three weeks prior to the next SEG meeting in New York.

A discussion of the problem of how to define noises and signal-to-noise ratio in magnetic recording brought out the suggestion that $S/N$ or figure of merit evaluations might not have much meaning. Instead, noises and infidelities should be listed separately from signal levels and distortions so that the user or customer could evaluate the meaning with respect to his own applications.

While it was agreed that I.R.E. and other standards should be used where possible, they should be carefully edited to weed out unnecessary parts and should be put into geophysical terminology as much as possible. The suggestion that terms relating more to the geophysical oscillogram should convey more information to the geophysicist met with a word of caution. Other forms of signal presentation are coming along and specifications relating more to the field of information theory might be more generally adaptable.

Mr. Thompson explained that he had delayed setting up the second sub-committee on Engineering Practices subject to recommendations from the main committee. He explained the differences in the functions of the two sub-committees; i.e., that the present sub-committee would be concerned only with definitions of terms used to specify the characteristics of magnetic recording equipment and with procedures for measuring these characteristics. The new committee would study instruments and their performance with particular attention to factors which might be standardized and at appropriate times make recommendations regarding standardization.

The chairman suggested that action on the second sub-committee on Engineering Practices be suspended until the next meeting. This was agreeable to most present except Mr. Begun. He felt that, since standardization is a long-term problem, action should be started now; that the proposals of the committee would serve as guide posts for future equipment design, tending toward uniformity where arbitrary decisions are involved. Recommendations of the committee, while not required standards in any sense, would provide a basis for a natural convergence toward standardization. He would be glad to write a letter to the committee suggesting what the sub-committee might do in this regard.

It was suggested that the manufacturers would benefit primarily, at first, from the actions of the Engineering Practices Sub-committee. The use of standards in form of multiple choice was proposed.

Mr. Thompson asked that the formation of the second sub-committee be postponed and requested that others write to him their ideas on the matter, both as to the responsibilities of the sub-committee as well as to its membership. It was felt that the chairman of the new committee should be a consumer, or user, of magnetic recording equipment, and that there should be on the committee representatives from each manufacturer who was interested.

The meeting then adjourned.

Respectfully submitted,
G. B. LOPER, *Acting Secretary*

ATTENDANCE AT MEETING

*Committee Personnel*

| | |
|---|---|
| K. R. Beeman | Southwestern Industrial Electronics Company |
| S. J. Begun | Clevite-Brush Development Company |
| J. D. Eisler | Stanolind Oil and Gas Company |
| G. M. Grosjean | Techno Instrument Company |
| B. D. Lee | The Texas Company |
| R. A. Peterson | United Geophysical Company |
| R. R. Thompson | Humble Oil & Refining Company |

*Alternates*

| | |
|---|---|
| Francis F. Campbell for K. M. Lawrence | Amerada Petroleum Corporation |
| John H. Hidy for J. E. Hawkins | Seismograph Service Corporation |
| G. B. Loper for J. E. White | Magnolia Petroleum Company |
| A. J. Seriff for F. A. Van Melle | Shell Development Company |

*Subcommittee on Definitions and Measurement Procedures*

| | |
|---|---|
| W. E. N. Doty | Continental Oil Company |
| Roger Harlan | Southwestern Engineering & Equipment Company |

*Observers*

| | |
|---|---|
| Jack Bogner | Minnesota Mining & Manufacturing Company |
| S. D. Elliot | Phillips Petroleum Company |
| Ralph A. Henderson | Minnesota Mining & Manufacturing Company |
| John Ohman | Southwest Research Institute |
| A. L. Parrack | The Texas Company |
| W. R. Stern | Brush Electronics Company |
| A. E. Tilley | California Research Corporation |
| W. Dale Wegrich | Minnesota Mining & Manufacturing Company |

## INTERIM REPORT OF THE MEMBERSHIP COMMITTEE OF THE SEG

The Membership Committee held a meeting in Dallas, Texas, November 18. In attendance were Francis Campbell, Tom Hall, and Bart Sorge. The problem of qualifications for Active Membership in the Society was discussed, and the following recommendations to the Executive Committee were agreed upon:

A. The Membership Committee approves the present qualifications for Active Membership in Article III, Section 4, which requires "work of a responsible nature calling for independent judgment and the application of geophysical or geological principles." In particular, the Committee does not favor a new membership classification intermediate between Active and Associate.

B. The Membership Committee believes that the members of the Executive Committee will have to continue to exercise judgment in the determination of the qualifications of an applicant in the future as they have in the past.

C. The Membership Committee recommends restriction of Active Membership to:

1. Those doing interpretation of original data, so that ordinarily only one or two men on a field party would qualify for Active status.
2. Those engaged in field operations who for eight years have exercised complete control of techniques which affect the quality of geophysical data. (This is not intended to modify the recognition of four years of college work toward the eight year requirement.)
3. Those in laboratory positions who for at least three years have worked on research or design projects in capacities which satisfy the requirements of Article III, Section 4.

It was decided to recommend to the Executive Committee that the above definitions be included in the Procedure Manual, as well as perhaps furnished to sponsors when acting on reference blanks in connection with applications for Active Membership.

A modification of the Constitution and/or Bylaws is not considered advisable at this time.

A request had been received from a member that the Society issue Membership Certificates, upon request, suitable for framing. It was decided to recommend to the Executive Committee that such Membership Certificates be designed and furnished members, providing requests from at least

ten other members are obtained for such certificates. It is also our recommendation that a charge be made for these certificates to cover the cost of same, as well as handling and shipping charges.

Another request was received from a member who suggested that the year of admittance to the Society be shown for every member on the Membership List following the member's name. The Committee decided not to recommend this matter.

The membership numbers assigned by the business office to all members, principally for identification purposes, were discussed. The Membership Committee has no objection to including the membership numbers on the Membership List. It is felt, however, that this is a problem for the Secretary-Treasurer and the business office.

A report on the Society's membership, received from the business office, was reviewed, as shown below:

REPORT ON MEMBERSHIP

*January 1 to October 31, 1954*

| | *Hon. & Life* | *Active* | *Assoc.* | *Student* | *Total* |
|---|---|---|---|---|---|
| Dec. 31, 1953 | 6 | 2,491 | 1,381 | 261 | 4,139 |
| Elected | 1 | 187 | 365 | 42 | 595 |
| Dropped | | 55 | 120 | 30 | 205 |
| Transferred to higher grade | | 1 | 66 | 67 | 134 |
| Deaths | | 3 | 2 | | 5 |
| | 7 | 2,619 | 1,558 | 206 | 4,390 |

The total additional members elected (595) indicates a continuing growth in membership. The number of members dropped during the interval of the report is unusually large, but is due to the efforts made on the part of the Committee to clear up the status of members no longer active and delinquent in dues. Also as a result of the Committee's efforts since the St. Louis meeting, the number of members owing dues for 1953 and 1954 has dropped from 167 to 41. During this same time, the number of members owing 1954 dues has been reduced to 91. This compares very favorably with the 211 dues delinquencies for the same period a year ago.

The problem of membership growth was discussed, and it was decided that conservative efforts should be continued to secure additional members for the Society. It was not considered advisable to engage in any high pressure large-volume membership campaign which would be detrimental to the interests of the Society's members as well as to the steady progress of the Society. There are four definite sources from which additional members for the Society can be obtained:

1. Members of local sections who are not members of the national organization.
2. Co-workers or acquaintances of members.
3. Non-members attending national or regional meetings.
4. Students.

In connection with the members of local sections who are not members of the national organization, rosters of membership were obtained from all local sections. These were carefully checked against the latest membership information, and about one thousand members of these local sections not now members of the national organization were mailed a letter of invitation to join the national Society, together with an application blank. To date this effort has resulted in the business office receiving seventy-one membership applications, fifty for Active and twenty-one for Associate Membership.

In order to reach the second group of potential members, a short letter has been prepared, with a membership application attached, which will be sent shortly to all members of the Society by the business office.

In order to reach the third group of potential members, requests have been and will be made at local and regional meetings to furnish the Membership Committee the names of non-members attending these meetings. Invitations to join will then be mailed to them.

The Membership Committee will not take any action in regard to securing additional members from the ranks of students at recognized colleges and universities due to the fact that the Student Membership Committee was recently reactivated under the able chairmanship of Fred Agnich. Should this Committee need any help, we will be very glad to cooperate with them.

Respectfully submitted,
BART W. SORGE

December 10, 1954

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## ABSTRACT OF MINUTES OF THE ANNUAL COUNCIL MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

BERKELEY, CALIFORNIA, DECEMBER 27 AND 30, 1954

The Council of the AAAS held meetings in Berkeley, California, on 27 and 30 December 1954. President Warren Weaver occupied the chair.

The principal items of business of a procedural nature were as follows:

1. Election of Dr. Paul B. Sears as President-elect.
2. Election of two members of Board of Directors:
   a. Chauncey B. Leake
   b. Margaret Mead.
3. Election of Vice Presidents and Chairmen of the Sections (18 Sections). For Section E, Geology and Geography, Prof. Carl Tolman, Washington University.
4. Nine new affiliates were then elected, including the Association of Geology Teachers (USA). The figures on affiliated and associated societies are as follows:

| | |
|---|---|
| Affiliated Societies | 163 |
| Affiliated Academies of Science | 42 |
| Associated Societies | 53 |
| Total | 258 |

5. Changes in Bylaws were aprroved relating to geographic division memberships and expenses thereof.
6. The following resolution was passed:

"There is growing concern over the procedures under which scientists are judged worthy of receiving federal money for unclassified research which does not involve problems of national security.

"It is understood that this matter is being studied by representatives of government agencies.

"The Board of Directors of AAAS and its Council urge the adoption of a uniform policy by all government agencies making grants for, or otherwise supporting, unclassified research. Specifically, they recommend adoption of the policy under which the National Science Foundation operates in awarding grants for unclassified research.

"Under that policy, appraisal of merit of a proposal is based on the experience, competence, and integrity of the investigator, as judged by a panel of competent scientists who have a working knowledge of his qualifications.

"However, certain persons are excluded from financial support by the National Science Foundation. It will not knowingly make or continue a grant to a person who is an avowed Communist or who has been established through judicial proceedings as being a Communist. Neither will it make a grant to anyone who avowedly advocates change in the United States government by other than constitutional means, or to one who has been convicted of sabotage, espionage, sedition, or any similar crime involving the nation's security.

"Thus, the policy excludes certain classes of individuals from receiving public funds for research, even though this research is unclassified. Such exclusion is based only upon due

process of law. Except in cases of persons thus excluded, appraisals as to worthiness of applicants to receive government funds are made by qualified individuals exclusively upon positive criteria of experience, scientific competence, and integrity of the applicant."

7. The Building Committee reported that construction of the new Association headquarters would begin in April 1955. Cost of construction will be met from surplus in hand.
8. The Committee on Constitution, Bylaws, and General Operations gave a preliminary report.
9. Reports were given by the following committees:
   a. Publications
   b. Source Books in the History of Science
   c. Representatives on World Federations of Associations
   d. Fluoridation of Community Water Supplies.
10. The Committee on Resolutions reported as follows:
   a. Not in favor of a proposed resolution submitted by the Association of Scientific Workers.
   b. As individuals, recommended the formation of a committee of the Association on Biological Effects of Thermonuclear Weapons.
   c. A resolution of thanks to the Berkeley local committee and to the University of California.

ROLAND F. BEERS
SEG Representative on Council

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## ANNOUNCEMENTS

### JACKSON GEOPHYSICAL SOCIETY ORGANIZES

On Monday evening, January 24, 1955, 62 members of the geophysical and geological professions met in the Roof Garden of the Robert E. Lee Hotel in Jackson, Mississippi to hold an organizational meeting for the proposed Jackson Geophysical Society. A constitution was adopted and the following officers were elected: Fred G. Knight, The Ohio Oil Company, President; Phil P. Gaby, Delta Exploration Company, Vice-President; and Robert R. Phillips, Honolulu Oil Corporation, Secretary-Treasurer.

The members decided to hold evening meetings, with the time and place to be announced. Members of the SEG and other interested earth scientists in the Jackson area are invited to participate in the activities of the new geophysical society.

### "CAREERS IN EXPLORATION GEOPHYSICS" TELEVISED

A telecast featuring a round table discussion of exploration geophysics as a career, moderated by Karl Dyk and R. A. Broding, members of the Geophysical Society of Tulsa, was presented by station KOTV, Tulsa, Oklahoma, during the 1954 Christmas holiday. Representatives from three Tulsa high schools participated in the discussion, and afterwards were dinner guests of the moderators.

The telecast was planned as the Tulsa section's part in the program being conducted by SEG to interest students in exploration geophysics.

### FELLOWSHIPS AND GRANTS

Continuing its program of financial aid to higher education in the U.S. and Canada, Socony-Vacuum Oil Company, Inc., and its affiliated companies, Magnolia Petroleum Co., General Petroleum Corp., and Mobil Producing Co., are contributing $324,000 during the 1954–55 school year for nearly 200 scholarships, fellowships, and grants to universities and colleges.

There are 21 research fellowships totaling $62,000 included in the program with funds going to both the schools and the students, and 64 scholarships amounting to $46,000 chiefly in exploration and production fields. Among the schools in the Southwest where Magnolia has fellowships or scholarship awards are SMU, the University of Texas, Rice, University of Oklahoma, Texas A. & M., LSU, Texas Tech, and the University of Kansas.

A total of $75,000 goes for fifteen grants for scientific and engineering research. The A.P.I. receives $70,000 for its program of fundamental research and special projects carried out in various colleges.

There are also 31 grants amounting to more than $71,000 for studies in economics, law, public health, and industrial relations, and to help libraries, museums, societies, and other projects.

Sixteen graduate students in seven different fields of study have received Stanolind foundation fellowships to 15 different colleges and universities for the 1954–55 academic year.

Robert S. Newhouse, director of industrial and public relations for Stanolind, reported that each of the 16 fellows was awarded a stipend of $1,500 plus tuition and fees at each school. Stanolind Foundation, Inc., was created and is supported by Stanolind Oil and Gas Company. Newhouse explained that the fellowship program was started in 1937 with one fellowship to the University of Texas.

Among those who have been awarded Stanolind fellowships is Robert Alwyn Bowers, who will carry on graduate study in geophysics at the University of California.

### OPENINGS IN GEOPHYSICS IN THE DEPARTMENT OF PHYSICS OF THE UNIVERSITY OF TORONTO

A lecturer in exploration geophysics is required in the Department of Physics, University of Toronto, Salary, $4,000.00. Acquaintance with gravimetric, electromagnetic and seismic instruments is essential, and field experience is desirable. The appointment is to commence September 1, 1955.

Applications are also invited for a Research Fellowship made available through funds given to the University jointly by the California Standard Company and California Research Corporation, stipend $1,800.00, open to students who have majored in physics and who preferably have some knowledge of geology. The research may be either in the field of exploration geophysics or in physics of the earth.

Apply to Professor W. H. Watson, McLennan Laboratory, University of Toronto, Toronto 5, Canada.

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## PERSONAL ITEMS

FREDERICK E. ROMBERG has been appointed manager of the Gravity Division of Geophysical Service Inc. He was formerly manager of the Southern Division, and will move to the new gravity division office at 3601 Sandman Street, Houston, Texas. RICHARD A. GEYER, formerly research geophysicist for Humble Oil & Refining Co., and a past Editor of GEOPHYSICS, has joined Geophysical Service Inc. as chief geophysicist of the Gravity Division. RAY H. WRIGHT has become manager of the Southern Division, replacing Mr. Romberg.

J. J. JAKOSKY, International Geophysics, Inc. President, announces the election to the directorate of JOHN J. JAKOSKY, JR., Vice-President and Treasurer, and JAMES G. JACKSON, JR., Secretary. Offices and laboratory are located at 1063 Gayley Avenue, Los Angeles, California.

S. E. SIMS has resigned as Chief Geologist of American Republics Corporation to accept a position as Assistant to the Managing Partner of Slick Oil Company, Ltd., 615 Melrose Building, Houston, Texas.

H. W. BROWN, a member of the first seismograph crew employed by The Carter Oil Company, and Exploration Manager for the company since 1952, has been named to the Board of Directors.

GEORGE E. WAGONER, another member of Carter's first seismograph crew, and a past President of SEG, has been transferred from the position of Western Division manager to the International Petroleum Co., Coral Gables, Florida, as Exploration Adviser.

EDWARD B. WASSON has joined Cosden Petroleum Corporation as Rocky Mountain Division Geologist with offices in the Denver Club Building, Denver 2, Colorado. He was formerly Division Geophysicist for The California Company in Denver.

V. W. TEUFEL has been named manager of the Southeastern Division of Geophysical Service Inc. at Shreveport, Louisiana, He was formerly a supervisor in the Southern division.

ROBERT S. KING, freshman at the University of Houston, has been awarded a $300 scholarship in geophysics by the Production Department of Sohio Petroleum Company. Following is a portion of the announcement published in "The Sohio Production News," company house organ.

The George E. Failing Company of Enid, Oklahoma, a wholly-owned subsidiary of Westinghouse Air Brake Company of Pittsburgh, Pennsylvania, has purchased from George E. Failing and his brother, Harry Q. Failing, all stock of the George E. Failing Supply Company, Ltd. of Edmonton, Alberta, Canada. The Canadian company was not included in the purchase made in April, 1953. Harry Failing will continue as general manager, and no other changes are contemplated in operating personnel.

GORDON K. TEAL, assistant vice-president, has been appointed to head the research division of Texas Instruments Incorporated. Previously Dr. Teal headed the materials and components research department.

H. M. THRALLS, Secretary-Treasurer of the Society of Exploration Geophysicists, has resigned as head of domestic exploration for Seismograph Service Corporation. He will continue with the company as a director.

R. W. MOSSMAN and R. B. BAUM have been elected assistant vice-presidents of Seismograph Service Corporation. Mr. Mossman is in charge of the northern division of the company's domestic exploration program and Mr. Baum heads the southern unit.

JEFF E. MILLER, JR., formerly Assistant Chief Geophysicist of the Seaboard Oil Company, Dallas, Texas, announces the opening of offices as consultant geophysicist. Mr. Miller was to be temporarily located at 7432 Villanova, Dallas, Texas.

STANLEY M. LEVENTHAL is president of Independents' Geophysical Surveys Corp., a newly-formed seismograph operating and consulting company with offices at 3019 Milam Street, Houston Texas, and 2237 Republic Bank Building, Dallas.

DONALD M. DAVIS, formerly a consulting geologist in Los Angeles, has accepted the position of Vice-President, Artnell Oil and Gas Co., Inc., 145 North Fifth Street, Coalinga, California.

IRA C. MAYFIELD is now president of Heiland Exploration Canada Limited, with offices at 502 42nd Avenue S.E., Calgary, Alberta.

C. B. TWARDOWSKI has become Chief Geophysicist for Century Geophysical Corporation of Canada, 1619 33rd Avenue S.W., Calgary, Alberta.

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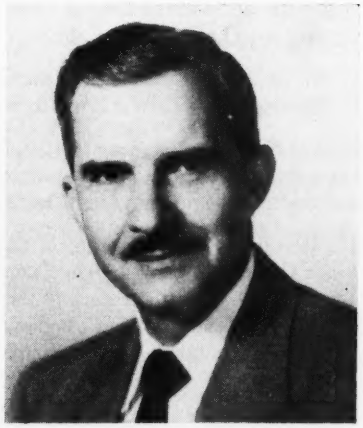
## NOMINEES FOR 1955–56 EXECUTIVE COMMITTEE

The following brief biographical sketches are presented to acquaint members of the Society with nominees appearing on the official ballot which will be mailed to all Active Members in good standing in June. Bylaws Article VII, Section 4, provides that "Prior to June 1, nominations in writing, signed by at least twenty Honorary Members or Active Members in good standing and accompanied by the written consent of the candidate, may be submitted to the President."

## FOR PRESIDENT

ROBERT C. DUNLAP, JR.



JOHN E. MCGEE

ROBERT C. DUNLAP, JR., was graduated from Southern Methodist University in 1933 with a B.S. and Honors in Geology, and took postgraduate work in geology and geophysics at Harvard University in 1933–1934.

In July, 1934 he was employed by Geophysical Service Inc., as a computer and was promoted to party chief in 1937. In 1943 he became a field supervisor and in 1949 was made vice-president in charge of the Pacific Coast Division of the company. He has worked in the Gulf Coast, Mid-Continent, Rocky Mountain and Pacific Coast areas. At present he is located in Dallas, Texas, as vice-president of domestic operations.

Mr. Dunlap is a member of the Society of Exploration Geophysicists and The American Association of Petroleum Geologists. He has served the SEG as secretary-treasurer of the Pacific Coast Section in 1947–1948; president of the Pacific Coast Section in 1948–1949; a member of the Standing Committee on Distinguished Lectures in 1949–1950; secretary-treasurer of the Society in 1951–1952; chairman, Standing Committee on Public Relations, 1953 to present; and general chairman, Mid-western Regional Meeting in Dallas, 1954. Currently, he is president of the Dallas Geophysical Society.

JOHN E. "SAM" MCGEE received the B.S. Degree in Electrical Engineering in 1922 from Tri-State College and the Degree of M.S. in Electrical Engineering in 1937 from Carnegie Institute of Technology. He was employed by the Westinghouse Electric and Manufacturing Company from 1923 to the end of 1930 in development and research work. In 1931 he joined the geophysical staff of the Gulf Research & Development Company at its Pittsburgh laboratory and has been with the Gulf organization since that time. In 1941 he became Party Chief on a seismic field crew from which he was transferred in 1944 to the Houston Division Office as a Supervisor. He was in charge of that office from 1949 to 1951, when he was transferred to the Gulf Oil Corporation as Chief Geophysicist for the Gulf Coast District of its Houston Production Division. He is now Division Geophysicist for the company's Houston Production Division.

He has been a member of the Society of Exploration Geophysicists since 1937 and is a charter member of the Houston Section of the Society in which he has served consecutive terms as Treasurer, Second Vice-President, First Vice-President, and President, completing the series in the spring of 1954. He has served on the Standing Committee on Membership of the Society. He is also a member of the American Association of Petroleum Geologists and the Houston Geological Society.

FOR VICE-PRESIDENT

DAVE P. CARLTON

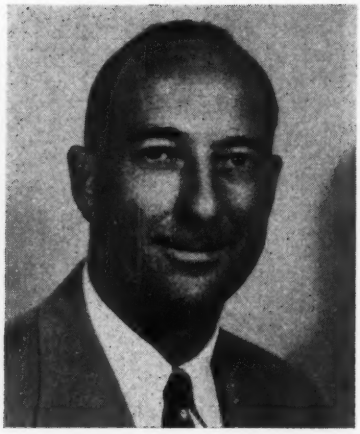
BART W. SORGE

DAVE P. CARLTON received his B.A. degree in Geology from Stanford University in 1915. He immediately went to work for Standard Oil Company of California as a geologist in the Coyote Hills. He resigned in 1916 to go into the mines in New Mexico and Nevada where he served until the war intervened in 1917. He joined the Humble Oil & Refining Company in May, 1919 as a geologist working out of the Fort Worth office. In 1924 he was assigned to the newly formed Geophysics group and became Chief Geophysicist in 1925, a position which he has held up to the present time. He is a member of the Society of Exploration Geophysicists and currently serving as chairman of the Society's Geophysical Case Histories Volume II. He is a member of the American Association of Petroleum Geologists, the American Institute of Mining & Metallurgical Engineers, and their local sections.

BART W. SORGE was graduated from the University of California at Los Angeles with an A.B. degree in Physics in 1933. He did postgraduate work in Physics at U.C.L.A., receiving an M.A. degree in 1934. Upon graduation, his geophysical experience began with the Rieber Laboratories as a development engineer, and later geophysical observer, party manager, and party chief. Since 1938 he has been employed by the United Geophysical Corporation, serving as a development engineer, computer, and party chief until 1943. At that time he became geophysical supervisor of United's western operations, and since 1947 he has been a vice-president of the company.

Mr. Sorge is a member of the Society of Exploration Geophysicists and the American Association of Petroleum Geologists. He has served the SEG as chairman of the Standing Committee on Safety since 1951, as a member of the Standing Committee on Radio Facilities since 1948, and as chairman of the Pacific Coast Regional Committee on Radio Facilities since 1948. As representative of the SEG Standing Committee on Safety he is also a member of the Central Committee on Accident Prevention of the American Petroleum Institute. In connection with the 1952 Annual Meeting in Los Angeles he served on the SEG Arrangements Committee and the AAPG Technical Program Committee. He served as Secretary-Treasurer of SEG 1953–1954, and currently is chairman of the Standing Committe on Membership.

## FOR SECRETARY-TREASURER



GEORGE A. GRIMM

JOHN A. LESTER

GEORGE A. GRIMM graduated from the University of Oklahoma in 1927, with an A.B. degree in Geology and was a graduate assistant in the Geology Department while taking graduate work in Geology the following year. He was employed by the Twin State Oil Company as geological scout in 1928, and from 1929 to 1931, as surface geologist. From 1934 to 1937 he was employed by Magnolia Petroleum Company and worked on a Torsion Balance crew in the Geophysical Department. In 1937, he joined Seismograph Service Corporation as a computer; from 1939 to 1950, served as a party chief. Since 1950, Mr. Grimm has been District Geophysicist for the Tide Water Associated Oil Company at Midland, Texas.

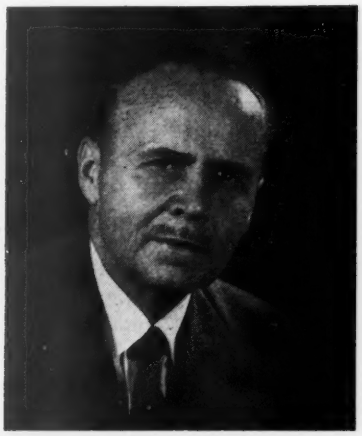
Mr. Grimm is a member of the Society of Exploration Geophysicists, The American Association of Petroleum Geologists, the Permian Basin Geophysical Society, and the West Texas Geological Society. As a member of the Permian Basin Geophysical Society he has served terms as Treasurer, 1st Vice-President, and President of the Society.

JOHN A. (JACK) LESTER received an A.B. degree in physics with minors in mathematics and geology from the University of Colorado in 1932. After completing a year of graduate work in physics he went to work for the Geophysical Research Corporation in 1933, as a helper on a seismograph crew. In 1937 he joined the Magnolia Petroleum Company as a seismologist. In 1939 he became a Seismograph Party Chief, and in 1943 was promoted to Supervisor in the Houston District. In 1946 he was transferred to Dallas, and in 1952 became Assistant Director of Geophysics for the Magnolia Petroleum Company.

Mr. Lester is a member of the Society of Exploration Geophysicists, the Dallas Geophysical Society and the Dallas Geological Society. He served as second Vice-President of the Dallas Geophysical Society in 1954, and is currently a member of the national society's Publicity Committee.

FOR EDITOR

THOMAS A. ELKINS



NORMAN RICKER

THOMAS A. ELKINS received his B.S. degree in 1927 and an M.S. degree in 1931 from Carnegie Institute of Technology. He has been employed by the Gulf Research & Development Company since 1930, with the exception of a period of study at Princeton University, from which he received an A.M. degree in mathematics in 1935. During World War II he was research physicist under a Gulf contract with the Office of Scientific Research and Development for the development of guided missiles. He is on leave of absence for the academic year of 1954–1955 for further study in mathematics at Carnegie Institute of Technology, with an appointment as project mathematician.

Mr. Elkins has devoted his attention primarily to problems of potential theory and statistics arising in the interpretation of gravity and magnetic data and has had a number of papers in this field published in geophysical journals. He is a member of the American Geophysical Union, the American Mathematical Society, the American Statistical Association, the Institute of Mathematical Statistics, and Sigma Xi, as well as of the Society of Exploration Geophysicists. He was the first chairman of the Society's Reviews Committee. He is at present a member of the Reviews Committee and Associate Editor (for Gravity Prospecting) of GEOPHYSICS.

NORMAN RICKER received the B.A. degree with Honors in Physics in 1916, the M.A. in 1917, and his Ph.D. in Physics in 1920, all from The Rice Institute. He held fellowships in mathematics and in physics during his graduate years and was an instructor in physics at Rice from 1919 to 1921. As a research engineer, 1921–23, at the laboratories of the Western Electric Company (now Bell Telephone Laboratories) in New York City he invented the paper cone type loud speaker. Employed in 1923 by the Humble Oil and Refining Company, he organized and directed their Geophysical Department, contributed to the development of refraction seismic prospecting, and first used radio in such operations. In 1925, he became a geophysical consultant. In 1927 he was engaged by the Hughes Tool Company to develop the Plunger Lift for pumping deep wells. In 1938 Dr. Ricker accepted a position as Senior Research Physicist with The Carter Oil Company where he is now employed at the research center in Tulsa. Here he has been engaged in further development of seismic processes and in mathematical researches on the wavelet theory of seismogram structure. Dr. Ricker served on the Honors and Awards Committee of SEG for five years (1949–54) and is at present Associate Editor of GEOPHYSICS for Seismic Theory and Fundamentals. As Distinguished Lecturer for the season 1953–54 he visited fourteen of our local geophysical societies lecturing on the wavelet theory. He holds membership in The American Physical Society, Acoustical Society of America, American Mathematical Society, American Association for the Advancement of Science, Society of Exploration Geophysicists, American Geophysical Union, Seismological Society of America, Geophysical Society of Tulsa (Pres., 1953–54), and Tulsa Philosophical Society (Pres., 1952–53).

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PUBLISHED BY THE EUROPEAN ASSOCIATION OF EXPLORATION GEOPHYSICISTS

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# SOCIETY OF EXPLORATION GEOPHYSICISTS

## MEMBERSHIP LIST[1]

February 1, 1955

| | |
|---|---|
| ##Honorary | 5 |
| **Life | 2 |
| Active | 2,610 |
| *Associate | 1,553 |
| #Student | 207 |
| Total membership | 4,377 |

## CONSTITUTIONAL PROVISIONS RELATING TO MEMBERSHIP

(As amended to August 26, 1948)

### ARTICLE III. MEMBERSHIP

SECTION 1. The membership of this Society shall consist of persons elected and qualified in accordance with the Constitution and Bylaws of this Society at the time of such election.

SECTION 2. The membership of this Society shall consist of Honorary Members, Active Members, Associate Members, and Student Members.

SECTION 3. To be eligible to election to Honorary Membership (##), a person shall, in the unanimous opinion of the Standing Committee on Honors and Awards and the Council, have made a distinguished contribution to geophysics or a related field which warrants exceptional recognition.

SECTION 4. To be eligible to election to Active Membership an applicant must have been actively engaged in practicing or teaching geophysics or a related field for not less than eight years (up to four years as a student in a recognized college or university may be counted toward this total) of which at least three years must have involved work of a responsible nature calling for independent judgment and the application of geophysical or geological principles.

SECTION 5. To be eligible to election to Associate (*) Membership, an applicant must be actively interested in geophysics.

SECTION 6. To be eligible to election to Student (#) Membership an applicant must be a graduate or undergraduate student in good standing in residence at a recognized university or college.

SECTION 7. An Honorary Member or Active Member shall enjoy all privileges of the Society. He shall be eligible to hold any office, to vote on all matters submitted to the membership, to petition the Council or Executive Committee on any matter, to sponsor applicants for membership and to publish his affiliation with the Society.

SECTION 8. An Associate Member or Student Member shall be entitled to attend the meetings of the Society, to receive its Journal and to purchase its publications, on the same terms as an Active Member. He shall have none of the other privileges of membership and in publishing his affiliation with the Society shall clearly indicate his grade of membership.

[1] This list is published from the latest information available to the Society for all who wish to refer to the professional and business affiliations of its members. It is not intended to be used for circularizing or soliciting purposes; information and rates for rental of the current mailing list for these purposes may be obtained from the SEG Business Office, 624 South Cheyenne, Tulsa, Oklahoma.

Any inaccuracies in the list should be reported to the Business Office. Members are requested to report changes in position promptly to the Business Office.

A

*ABBOTT, ROBERT F., *Computer*, Geophysical Service Inc., 5245 Kingwood Dr., St. Louis 23, Mo.

ABBOTT, WAYNE R., 2517 N. W. Grand Blvd., Oklahoma City, Okla.

*ABBOTT, WILLIAM C., Shell Oil Co., Box 2099, Houston, Texas

ABEL, KARL W., *Office Manager*, Mayes-Bevan Co., 305 Kennedy Bldg., Tulsa, Okla.

ACHESON, C. HAROLD, *Seismograph Research*, Imperial Oil Co., Cambourne Motor Ct., Calgary, Canada

*ACKERMANN, HERBERT J., JR., *Computer*, Lafayette Exploration Co., Box 555, SLI, Lafayette, La.

*ACKLIN, FLOYD, JR., *Dist. Geologist*, Richardson & Bass, 701 N. Canal, Carlsbad, N. M.

*ACREY, DONALD O., *Party Chief*, Rayflex Exploration Co., 612 Cordova St., Dallas, Texas

*ADAMS, GEORGE W., *District Sales Mgr.*, Canadian Industries Ltd., 10262 108th St., Edmonton, Alta., Canada

ADAMS, HAL ROBERT, *Geophysicist*, Sohio Pet. Co., Box 1477, Billings, Mont.

*ADAMS, HUGH M., JR., *Party Chief*, Reliable Geophysical Co., Box 450, Yoakum, Texas

ADAMS, JOHN A., *Seismic Supervisor*, Western Geophysical Co. of America, Rm. 211, Tower Bldg., 1669½ Chester Ave., Bakersfield, Calif.

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Riddell, C. E.
Rogers, George R.
Romberg, Marvin
*Seamans, F. Augustus
Schmidt, Robert L.
*Schweiger, Charles E.
*Shafer, William E.
Shepherd, C. K.
Short, Don C.
Smith, Charles B., Jr.
Smith, Melvin M.
Spencer, Jesse E.
Spencer, Leslie C.
*Storch, Robert H.
*Taiclet, Daniel Alvin
*Tarbox, George E.
*Thomason, Herman B.
Thompson, James E.
Travis, Fred L., Jr.
*Veneklasen, Gordon O.
Versaw, Francis Raymond
Wagoner, George E.
Wantland, Dart
*Warrick, Richard E.
*Wasson, E. B.
Watson, James M.
Wilkinson, A. L.
*Wilson, James E.
Wurth, Wm. H.

**Denver Federal Center**
*Miller, Raymond E.

**Durango**
*Freitag, William G.
*Hanrahan, Thomas N.
*Hinson, Vernon F.
Kennedy, Edward P.
*Lowe, Donald Paul
Osterhoudt, Walter J.
*Slattery, Gerald F.
Thomas, Robert P.

**Estes Park**
*Closs, John D., Jr.
♯Khan, Mayan I.

**Fort Morgan**
*Ingle, Gerald W.

**Gilman**
Westphal, Warren H.

**Golden**
♯Afra, Thomas S.
*Anderson, Thomas P.
♯Banks, Richard B.
♯Birdsall, Edwin F.
*Coolbaugh, David F.
*Gude, Arthur J., III
*Hasbrouck, Wilfred P.
Hayes, John R.
Merideth, George T.
♯Pickett, Geo. Richard
♯Risley, Edward W.
♯Sonido, Ernesto Pobre
♯Tullis, Thomas M.

**Grand Junction**
*Bales, Henry R., Jr.
*Black, Rudolph Allan
Blake, E. F.
*Botkin, John N.
*Chandler, William J.
*Cutter, Russell C.
Donnerstag, Ogukuo
Donnerstag, Philip
Nicol, A. J.
*Roller, John C.

**Greeley**
*Endacott, Foster E., Jr.
*Wimber, Max E.

**Lakewood**
Kretz, R. L.

**Leadville**
*Wells, Herbert C.

**Loveland**
Degood, R. G.

**Montrose**
Gibbs, Kenneth E.

**Springfield**
Burden, Alton O.

**Uravan**
*Ekren, Elinar B.

**Wheatridge**
Lomax, C. J.

## CONNECTICUT

**Green's Farms**
Zavoico, Basil B.

**Ridgefield**
Doll, Henri G.
Ferre, Maurice C.
Legrand, J. C.

**Winsted**
♯Angino, Ernest E.

## DELAWARE

**Wilmington**
*Budd, Montgomery R.
Johnson, Norman G.
Lawrence, Robert W.
*McKinney, Charles D., Jr.
Weiss, Oscar

## DISTRICT OF COLUMBIA

**Washington**
Barnes, David F.
Bates, Charles C.
Brenner, Morris
Brown, C. Bradner
Gould, Martin J.
Henderson, Roland G.
*Heppner, James P.
Hoffer, C. W.
Hoover, Herbert, Jr.
*Jackson, Wayne H.
Joesting, Henry R.
Kendall, James M.
King, Elizabeth R.
Klaasse, James M.
Manger, George E.
McGhee, George C.
*Oliver, Howard W.
Pakiser, Louis C., Jr.
Rabbitt, Mary Collins
Swartz, J. H.
Zietz, Isidore

## FLORIDA

**Arcadia**
Mogck, A. R.

**Clearwater**
*Weaver, Irvin P., Jr.

**Coral Gables**
Blanchard, William G.

**DeFuniak Springs**
*Drury, Lynn J.

**Fort Lauderdale**
Freeman, Lawrence I.

**Ft. Myers**
Thomas, Ray

**Ft. Pierce**
Shannon, Charles A.

**Homestead**
*Weiss, Ben

**Marianna**
Crow, B. M.
*Ellis, Thomas J., III

**Miami**
Gilmore, Marion H.
*McCord, J. L.

**Miami Shores**
*Devos, Lawrence S., Jr.

**St. Petersburg**
Sauls, James L., Jr.

**Tallahassee**
Olander, Amor M.
Shapard, Charles A.

## GEORGIA

**Athens**
♯Bowen, Richard L.

**Atlanta**
Straley, H. W., III

**Whitesburg**
♯Hilley, James Franklin

### IDAHO

**Twin Falls**
Brodine, Robert V.
*Wallace, John J.

### ILLINOIS

**Belleville**
#McEvilly, Thomas V.
#Uhley, Robert Phil
**Chicago**
Davis, Donald M.
*Heidt, Malcolm J.
#Nelipovich, Daniel J.
*Stuebing, Richard Hardin
**Collinsville**
#Bollinger, Gilbert A.
**Evanston**
Krumbein, Wm. C.
Siegert, A. J. F.
*Slack, Howard A.
**Forest Park**
*Rutkowski, Chester
**Mascoutah**
*Trammell, Detroy
**Mattoon**
Dawson, Woodson H.
Josselyn, Walker H.
Rosaire, C. G., Jr.
**Mt. Carmel**
Sharp, C. Sheldon
*Stein, Clarke
**Mt. Vernon**
Rutherford, H.
**Mundelein**
*Leaf, Howard
**Roodhouse**
*Dunaven, William A.
**Sidney**
Everitt, James
**Springfield**
*Spanski, Robert F.
**St. Elmo**
Adams, Wallace W.

### INDIANA

**Evansville**
Combs
*Slanis, Albert A.
**Terre Haute**
*Seeburger, George Bernard

### IOWA

**Ames**
Roy, Chalmer J.
#Spaeth, Mark G.
**Harlan**
*Christensen, Fred A.

### KANSAS

**Alexander**
*Vague, C. E.
**Ft. Riley**
#Blazel, Carl Louis
**Garden City**
*Gauvin, Gerald R.
**Great Bend**
*Casteel, Hoyt F.
*Dorsey, Mayo B., Jr.
*Downs, William M.
#Evenson, Raymond M.
Martin, Richard G.
*Mix, Leo R.
**Independence**
*Tipton, Dee Leroy
Turner, Gerald L.
**Kansas City**
Jones, Harold H.
**Kingman**
*Michael, Thomas G.
**Kinsley**
*Spencer, James F.
**Liberal**
Staples, Guy W.
*Steward, Lyle W.
**Manion**
*Washburn, James Carroll
**Norton**
*Spalsbury, William A.
**Osawatomie**
*Chamberlin, Nicholas J.
**Pratt**
Bratt, Curtis Carrol
**Russell**
*Richards, Bill A.
**Wakeeney**
*Bernard, Leonard
**Wichita**
Ballard, James A.
*Brooks, Dilliard Lee
Care, John L.
*Cherry, Charles L.
#Dunwoody, Robert H.
Evans, David Lecount
*Fuqua, Henry H., Jr.
Glover, Robert H.
Henderson, Marion R.
Hill, John Robert
*Knight, William V.
#Lewis, Paul K.
Mercier, Vincent J.
*Schaefer, Leo J., Jr.
Trombla, Lynn B.
*Ver Wiebe, Walter A.
Wallace, Charles H.
Williams, Charles C.

### KENTUCKY

**Mayfield**
*Evens, Joseph H.

### LOUISIANA

**Abbeville**
Albright, Thomas Buford
**Baton Rouge**
Cannon, Mike S., Jr.
*Drews, Theodore E.
Hughson, Barrett B.
Johnson, Byron K.
Kroger, W. L.
Lipscomb, John W.
McDougall, John E.
Ogden, W. Wesley
#Stengel, Eugene
Webster, Felix H.
**Bunkie**
*Eversull, L. J.
**DeRidder**
Whitsitt, C. D.
**Franklin**
#Tomlinson, E. L.
**Gonzales**
*Parker, Everett H., Jr.
**Hammond**
Courtney, E. A.
**Harvey**
*Kuhu, William A.
**Homer**
*Mitchell, Gerald E.
**Houma**
Augustat, George
*Back, William D., Jr.
Crandall, Robert E.
Elston, Chris H.
*Fleming, Dewitt P.
Harper, Wilbur L.
*Knittle, Richard B.
Lewis, Karl E.
Martin, Arthur G.
*Mitchell, James W.
*Sadler, John W.
**Jennings**
*Jones, Walter Dee, Jr.
*Kent, Robert F.
**Kenner**
Flatley, D. J., Jr.
**Lafayette**
*Ackermann, Herbert J., Jr.
Aderman, C. V.
*Bailey, Frank Rose, Jr.
*Cocovinis, Dimitri B.
*Conley, H. R.
*Coons, James D., Jr.
Current, Eugene L.
Darden, David B.
Evans, Joseph B., Jr.
*Fee, Charles F., Jr.
*Granberry, William S.
*Harbison, Reginald N.
Jeffers, Paul H.
*Lee, Frank W.
Lee, J. E., Jr.
Moore, James M.
Palmer, John C.
*Parker, John Chapman
Patterson, W. L.
Reese, W. H.
Ricketts, E. L.
*Roberts, Lee Roy
Rowe, Ural A.
Schneider, John J., Jr.
Smith, Ralph T.
Tilley, G. E. (George)
Wells, L. H.
White, William H.
**Lake Charles**
*Auster, Edward C., Jr.
Boutte, H. G.
#Fefer, Joseph M.
Hammons, F. H.
*Jameson, John A.
Jones, Thurman L.
*Laker, John D.
*Mashburn, Clifford H.
Moore, James A.
*Novak, Daniel J.
Reichert, H. C.
Russek, I. W.
Schuster, Gerhardt H. W.
*Shaw, Maynard D.
*Smith, Jennings G.
Texter, John W.
Walling, Ray W.
**Leesville**
*Bourgeois, Alvin J.
**Metairie**
Wiley, W. B.
**Monroe**
Nichols, E. Turnley
**Montgomery**
*Giddens, O. F.
**Morgan City**
#Alexander, Michael, Jr.
**Natchitoches**
Harms, James R.
**New Iberia**
*Persinger, Richard R.
*Provensal, Louis V.
*Richard M. W.
Treybig, B. H., Jr.
*Wilkinson, Raymond W.
*Brown, Warren A., Jr.
**New Orleans**
*Adams, Leland C.
Allen, Clark E.
Anderson, Edmund H.
Atwater, Gordon I.
*Bell, John H.
*Berry, George F.
*Boebel, Richard Wallin
Brown, L. I.
*Burke, Thomas M.
Burton, Gerald A.
Butler, Robert
Calahan, L. W.
Callahan, Janie L.
Chalmers, H. B., Jr.
Cobena, L. W.
*Coffeen, James A.
*Courtney, Chyde J.
*Cowart, H. M.
Cowie, Roger H.
*Diment, Wm. H.
*Dingman, Milford H., Jr.
*Donohoe, Henry Thomas
Duty, W. B.
*Etnyre, John B.
Fennessy, William J.
*Fitzpatrick, Harvey J.
*Franson, Guy W.
Frey, M. Gordon
*Funkhouser, Lawrence W.
Girard, Cecil Meshew
Harang, Jack F.
Harris, J. A.
Hazen, William G.
Holekamp, O. G.
Hutson, Carl Monroe
Jamison, Roy Bland
*Knowles, Ruben Wesley
*Kringel, Howard E.
*Lilley, Charles C.
*Lucas, Dennis R.
*Mabry, Delord R.
Macgregor, Joel Edward
Mann, Neil W.
Markley, Leo A.
*May, T. O.
McCabe, Walter A.
*McMaster, J. T.
Meitzen, J. B.
Morgan, A. L., III
Morgan, George O., Jr.
Murray, Irvin B., Jr.
*Nicholls, Robert Louis
Oudt, F. W.
Petersen, Harluf C.
Pincomb, E. M.
*Pirsig, Gerald F.
Poirier, O. A., Jr.
#Rauschenback, Otto Robert, Kearny
*Rodrigue, L. G.
Russell, Steward Leo
*St. Romain, Joseph B.
*Schorre, Barthlome
Shannon, Ellis H.
Sheriff, Robert Edward
*Smith, Darrell E.
Smith, F. A.
Smith, Merrill
Sprague, Robert L.
Stouse, Maurice J., Jr.
Stumpf, L. Beverly
Suggs, Robert L.
Upshaw, R. W.
Utterback, D. D.
*Watson, Robert E.
*Wegener, R. H.
Wells, Kenneth R.
Williges, William A.
Wilson, David S.
Winters, Rayford W.
Wright, Ronald E.
**New Roads**
*Wheat, James M.
**Opelousas**
*Eubank, John T.
**Port Allen**
Swearingen, A. C.
**Shreveport**
Akin, Ralph H.
Appendino, John
Baker, Glenn J.
*Bragg, Charles P.
Carter, R. W.
Caster, E. L.
*Clark, John W., Jr.
Clark, William W.
*Clarke, Clem S.
Cooke, John Graves, Jr.
Barret, Wm. M.
Bloomer, P. A., Jr.
*Browder, Walter Clarence
Bryan, Carl L.

Buckingham, W. T.
Burroughs, B. B.
Butt, Harding
Cramer, Neal Parker
*Davis, Billy G.
*Dinstel, Woodrow L.
Duncan, James P.
Eaves, Everett
*Farley, James F.
Fazakerly, W. B.
Ferber, Herbert
Ferguson, J. G.
Fischer, L. F.
Forgotson, James M.
*Fox, Bruce W.
#Frazier, Meriwether Lewis
Goebel, Lawrence A.
Grant, Henry Lowry
Harris, John
*Hill, Robert B.
#Houching, Guy M., Jr.
Howard, G. C.
*Jones, John Paul
*Jordan, James B.
*Kell, James A.
Kidd, Robert L.
*Langston, B. L.
#Lurton, Nelson E., Jr.
Mackey, Patrick E.
Martin, Walter E.
*Mayhew, C. J.
McCullers, Wm. E.
*McCutchen, Edgar O.
Morriss, Herbert A., Jr.
Nicholls, Charles W.
Owen, H. J.
Proffitt, Jack, M.
Rosenkrans, R. R.
Schlundt, Herbert
Smithwick, H. B.
Spradlin, S. T.
Strange, Booth B.
Teufel, Virgil W.
*Tilleux, H. O.
Tucker, Bill C.
Wade, R. T.
Wagner, William C.
Walker, J. R.
Walton, Britain W.
Wardell, Richard H.
Wilson, Richard M.
Woodyard, K. C.
Young, Jackson S.

**Sulphur**
*Campodonico, M. A.

**Thibodaux**
*Barnett, Robert Blake
*Guyton, William H., Jr.
*Lake, Sam R.
*Last, Leland A.
Smith, Ross, Jr.
*Thomas, Eugene B.

**Vidalia**
*Campbell, Richard A.

## MARYLAND

**Aberdeen**
*Murphy, William H.

**Aberdeen Proving Grounds**
Perkins, Beauregard, Jr.

**Baltimore**
Rim, Herbert G.
Roman, Irwin

**Bethesda**
Melton, Ben S.

**Hillcrest Heights**
*Clements, Donald H.

**Kensington**
Balsley, James Robinson, Jr.
Doolittle, Russell C.

**Owings Mills**
Lee, Frederick W.

**Silver Spring**
Lipson, Edward
Martin, James M.
Willis, Floyd, Jr.

**Takoma Park**
Newquist, John W.

## MASSACHUSETTS

**Allston**
#Treitel, Sven

**Arlington**
#Walsh, William P.

**Bedford**
*Fava, James A.
#Hofmann, Renner B.

**Boston**
#Leith, Thomas H.
#Pantall, Jack T., Jr.

**Cambridge**
#Bowman, Robert
Crary, Albert P.
#Fink, Don R.
*Goldstein, Norman
#Hallof, Philip
#Hanson, Roy E.
Haskell, Norman A.
Hawkes, H. E., Jr.
*Joyner, William B.
Leet, L. Don
#Lopes-Linares, M.
*Moore, James Robert, III
#Rostoker, Mendel D.
*Simpson, Stephen M., Jr.
*Vozoff, Keeva

**Lexington**
#Burrows, Lees J., Jr.

**Lynn**
#Davidson, Maurice J.

**Newtonville**
#Madden, Theodore R.

**North Adams**
*Geiser, David T.

**Waltham**
Peoples, J. A., Jr.
#Whipple, Arthur Paul

**Weston**
Linehan, Daniel

**Woods Hole**
Hersey, J. B.
Officer, Charles B., Jr.

**Worchester**
*Horner, Robert S.

## MICHIGAN

**Ann Arbor**
Wilson, James T.

**Detroit**
Mandlebaum, Hugo

**Grand Rapids**
*Kolb, John

**Crosse Pointe**
*Margenau, R. E., Jr.

**Houghton**
Bacon, Lloyal O.
#Brooke, John
#Cleary, Gerald A.
#Elliot, Charles Lothrop
Longacre, William A.

**Ishpeming**
Boyum, Burton H.

**Jackson**
*Riedel, Robert W.

**Painesdale**
#Frantti, Gordon E.

## MINNESOTA

**Buhl**
Bickford, Kenneth F.

**Minneapolis**
Armstrong, Lee C.
*Cornell, James R.
Mooney, Harold M.

**South Moorhead**
*Humphrey, William Robert

## MISSISSIPPI

**Biloxi**
*Raffalovich, Francis D.

**Brookhaven**
Barthelemy, J. E.

**Calhoun City**
*Blaik, Maurice
*O'Connor, Robert B., Jr.

**Columbia**
*Conner, Joseph C., Jr.

**Columbus**
Bloodworth, Dennis Alvin, Jr.

**Gulfport**
#Murphy, William E.

**Hattiesburg**
Lowery, R. A.

**Hazlehurst**
*Smith, Clifton Douglas

**Holly Springs**
*Patterson, Sam W.

**Jackson**
Allred, Willard A.
*Beall, Edward W.
Butler, Mark D.
Chang, T. Y.
Cole, Ralph C.
Cook, D. E.
Crager, John A.
*Diamond, Paul E.
Duby, Bryan A.
Forward, Fred
Gaby, Ewin D.
Gaby, Phil P.
*Graham, Maxwell O.
Hall, J. A., Jr.
Harris, Holmes E.
*Jones, Sargent F., II
*Kerr, William W.
Knight, Fred G.
LeBay, William D.
*Long, Russell L.
*Myers, M. D.
*Phillips, Cecil Toney
Phillips, Robert
*Phipps, Rollin E.
Pretzer, Dwayne L.
#Redish, William L.
*Robinson, William J.
*Wallner, Jack D.
*Walton, William M., Jr.

**Keesler A.F.B.**
*Bender, Hubert L.

**Laurel**
*Schuller, Jerome Albert

**Lexington**
*Hughes, Leslie Clifton

**Lumberton**
*Hill, Ralph R.

**Magee**
*Sigle, Gene C.

**McComb**
*Golson, Rex, Jr.
#Riley, Louis E.

**Natchez**
*Fusso, Joseph W., Jr.
Gulmon, G. W.

**Port Gibson**
Jameson, W. W.

**Purvis**
*May, John E.

**Wayside**
*Potter, Julian F.

**West Jackson**
*Humphris, Curtis C., Jr.
*Lyth, Ambrose L., Jr.
McDaniel, C. M., Jr.
*Province, Harold E.
*Ramsdell, Jack A.
Totten, Stanley W.

**Yazoo City**
Harwell, Robert B.

## MISSOURI

**Brentwood**
#Wiggins, John H., Jr.

**Ft. Leonard Wood**
Kettle, Robert W.

**Humansville**
*Ray, Bill B.

**Joplin**
*Cash, Robert O.
*Marsh, Wm. T.

**Kansas City**
*Leininger, Robert J.

**Latour**
*Feeback, Lawrence D.

**Richmond Heights**
#Riley, James T.
#Riley, Robert C.

**Rolla**
Gabriel, V. G.

**Savannah**
*Yost, Carl E.

**St. Louis**
*Abbott, Robert F.
#Adams, William Mansfield
#Algermissen, S. Theodore
Blum, Victor J.
#Chang, Feng-Keng
*Cherry, Jesse T., Jr.
#Daly, Charles M.
*Englehardt, James R.
#Forrest, Michael C.
#Ganguli, Debkumar
#Hasenpflug, Harry J., Jr.
#Haug, Ronald E.
Honnell, Pierre M.
Macelwane, James B.
#Miatech, Gerald James
*Miller, Cecil A.
#Mudra, Paul J.
*Nuttli, Otto William
#Opp, Albert Geelmuyden
#Saunders, Barry C.
Scharon, LeRoy
*Smith, Larry W.
#Webb, John P.
#Young, Durward D., Jr.

**University City**
#Davit, William A.
Kisslinger, Carl

**Webster Groves**
#Stolwyk, David J.

## MONTANA

**Billings**
Adams, Hal Robert
Albers, W. R.
*Allen, Sam W., Jr.
Barron, C. E.
Bartel, Edwin
Black, Arthur W.
*Bozman, Julius R.
Cloepfill, Gordon D.
Crary, Donald
Crowder, H. V.
Cummins, Dean L.
Davis, Charles A.
Davis, J. Lee
*Dinkins, Donald E.
*Fauser, Walter, B., Jr.
Fellows, Robert A.
Fruehling, S. W.
Gemmer, R. W.
*Gilstrap, John Samuel
*Greenlee, Darrell Ray
Greenlee, Paul
*Harris, Ross Allen
Herr, H. K.
Hoffman, John C.
Holloway, William L.
Hull, N. L.
*Hunter, Dean T.
*Kerns, Clyde W.

King, Thomas C.
Kirby, Gordon
*Kurfess, James A.
Lewis, A. V., Jr.
*Livo, George
Manos, Sammy G.
Marsh, Samuel R.
McGee, N. W., Jr.
Megason, Leland G.
Menefee, J. C.
Moore, C. F., Jr.
*Newell, James W.
Newton, Austin James, Jr.
*Oakley, William M.
Parker, John M.
*Paterson, Walter D.
Pearce, Warren N.
Penny, Robert T.
Peters, Jack W.
*Peterson, Wendell E.
Porter, Hough, Jr.
Reeves, F. R.
Rouse, John T.
Schombel, Leonard F.
Shay, Daniel C.
Sides, Joe
Snodgrass, D. D.
*Sonnenberg, Frank P.
Spaulding, James B.
Steel, D. M.
Thompson, Andrew A.
Thomsen, Harry L.
Wickerham, Maurice D.
Willcockson, James R.
Wilson, E. E.

**Broadus**
Smith, Hobart C.

**Chinook**
*Dill, James B.
*Varva, Joe F., Jr.

**Chotean**
*Bursk, Phillip H.

**Cut Bank**
*Jefferies, Robert L.
*Nichols, Thomas C., Jr.
*Peffer, John C.
Rhodes, Cecil T., Jr.
*Root, James R.
*Wicker, John B.

**Glasgow**
Stewart, Calvin D.
Strozier, Orville A.

**Glendive**
Price, David P.

**Great Falls**
*Gribi, Edward A., Jr.
*Meadows, Harold M.
*Thirkhill, Edward R.

**Harlem**
Havener, John H.

**Havre**
Johnson, Melvin C.

**Imperial**
*Bostick, Paul J.

**Miles City**
Buchner, Harry M.
Colvin, C. E.
Cox, Charles B.
*Langstroth, Ward T.
*Park, Harold B.
*Smith, David J.
*Young, Malcolm Arthur

**Wibaux**
Daly, T. E.
*Kruppenbach, John Albert

## NEBRASKA

**Omaha**
Barton, Jackson M.

**Sidney**
Gillig, Frederick Samuel
Gilliland, J. R.
*Myers, Jack W.

## NEW JERSEY

**Bayonne**
#Knapp, Gregory A.

**Millville**
#Williams, Alfred E.

**Princeton**
*Bonini, William E.

## NEVADA

**Elij**
*Eckert, Stacey Eugene, Jr.

**Ely**
Brumbaugh, Harold G.
Holder, Homer C.
Schroll, Charles L.

**Reno**
Stephenson, Edgar Lee

**Wells**
Parkhill, J. Brooks
*Vetten, William

## NEW MEXICO

**Albuquerque**
*Birdseye, Henry S.
Lohse, John M.
*Malovich, Ernest J.
Perret, W. R.
*Radic, Kenneth V.
*Stout, Allison B., Jr.
Whelan, Mark

**Artesia**
*Johnston, Jerry Burk

**Aztec**
*Coan, G. B.
Copeland, H. V.
McConathy, Warren J.

**Carlsbad**
*Acklin, Floyd, Jr.
*Barmore, Clarence E.
Corbin, L. P., Jr.
Jennemann, Vincent F.
##Pratt, W. E.
Witherspoon, Dwayne Russell

**Eunice**
Files, Wiley Frank

**Farmington**
Scott, D. L.

**Hobbs**
*Coburn, Haskell
*Hoagland, William N.
Jones, Robert W.
Moore, J. Hiram
*Thompson, Grady
*Wicker, Marshall C.

**Jal**
*Andersen, Robert J.

**Lovington**
*Bills, Eugene S.
*Buelow, James W.
*Burton, David Lester
Epperson, R. S.
*Field, William L.
*Graham, Floyd B.
*Heinrichs, Christian C.
*Lambright, Orbie N.
*Miller, Dean Hudson

**Roswell**
*Bradley, Robert K.
*Broman, William H.
*Danz, D. W.
*Finley, J. E.
Gilmore, Robert A., Jr.
Hughes, W. R.
*Kessler, Eugene L.
Livingston, E. C.
Long, Clarence J.
Mamantov, Ilya
McCoy, William G.
*McGarry, William Andrew
McKenzie, Chessley E.
Molinar, J. J.
*Richardson, William E.
Scaife, W. P.
*Smith, Robert V.
Sullivan, Daniel H.
*Waggoner, James Laverne
Willner, Carl A.

**Socorro**
*Gourley, Lloyd E., Jr.
*Holmes, Charles R.
#Kintzinger, Paul R.
Vacquier, Victor

## NEW YORK

**Amawalk**
Kelly, Sherwin F.

**Brooklyn**
*April, Howard L.
*Kelly, Patrick F.

**Dobbs Ferry**
*Tolstoy, Ivan

**Fayetteville**
Nash, Cleve C., Jr.

**New York**
#Beckmann, Walter Chas.
*Burgunker, Mark E.
Cash, Harvey, Jr.
#Conley, C. D.
Dresbach, C. H.
Flittie, Clifford G.
Fryer, Theodore B., Jr.
Gibbon, H. A.
Hardy, W. W.
Hazen, Geo. H.
Helser, Edwin F.
Jackson, Robert W.
*Kaehn, Charles H.
Kaufmann, G. F.
Knebel, George Moses
Kogbetliantz, Ervand
Lay, Roy L.
Lynch, J. Joseph
*Novotny, Robert T.
Olson, Walter S.
*Racek, Edward W.
*Scott, Robert Franklin
Slotnick, M. M.
Smith, Maurice G.
Tucker, Lewis R.
Vajk, Raoul
Van Der Sleen, N.
White, Rex H.
Whiton, Herman F.
Wise, Richard A.

**Palisades**
#Drake, Charles L.
Ewing, Maurice
#Heezen, Bruce C.
#Miller, Edward T.
*Oliver, Jack E.
Press, Frank
#Sutton, George H.
Worzel, J. Lamar

**Richmond Hill**
Fredukowicz, Waclaw

**South Glens Wall**
#Orsini, Nicholas A.

**Syracuse**
*Kopka, William

**Troy**
Beers, Roland F.

**Wellsville**
*Young, Wilber H., Jr.

**White Plains**
Hotchkiss, Hugh C.

## NORTH CAROLINA

**Hendersonville**
Taney, Norman E.

**Raleigh**
Miller, E. L., Jr.

## NORTH DAKOTA

**Bismarck**
Armstrong, Orven H.
*Cameron, John B.
Howe, Ralph H.
Orcutt, Harry Dale
*Owen, D. E.
*Owens, Michael R.
Rader, Miles T., Jr.
*Richardson, Alan
*Smith, Oscar Edwin, Jr.
*Smucker, John Reed
Vanderbeek, James Wilson
#Zieve, Robert L.

**Dickinson**
*Hayes, Quin
#McCormick, John J.
Prichard, Harold H.

**Grand Forks**
#Iverson, Walter D.

**Minot**
Hammon, Dean H.

**Parshall**
*Hampton, Jack Herst

**Watford City**
Sackett, L. H.

**Williston**
Brensing, Vernon Lee
House, J. P.
*Miller, Lloyd C.
*Oram, Peter M.
*Pick, Albert L.

## OHIO

**Cleveland**
*Begun, Semi Joseph
*Berggren, Charles F.
Birkenhauer, Henry F.
*Kostra, Walter
Walter, E. J.
*Woods, John D.

**Columbus**
Heiskanen, W. A.
*Hickle, William G.
*Pincus, Howard J.

**Dayton**
Koenig, Palmer E.

**Findlay**
Konkel, Philip M.
Yost, W. Jacque

**Lakewood**
*Barry, Kevin M.

**Willoughby**
*Willis, David E.

## OKLAHOMA

**Ada**
Martin, Dick

**Altus**
*Barnes, George Lewis
*Goin, Milton D.

**Anadarko**
*Black, Robert J.
*Ruminer, Donal E.
*Whitmore, Richard E.

**Antlers**
Olson, Odell C.

**Ardmore**
*Carmack, Roy P.
Cowden, Robert W.
Kirk, David K.
*Pierson, Jack N.
Wallace, Bennet Warren

**Bartlesville**
*Allen, William E.
Bondurant, J. E.
Bradley, R. M.
Courtier, W. H.
Crenshaw, C. C.
Dissler, Ernest W.
Elliott, Sam D.
Ericson, Harry B.
*Graves, John Milton
Hintze, A. J.
Johnson, Earl W.
Leisure, John, Jr.
McNally, Perry Michael
Mendenhall, Harold L.
Miller, Vincent
Morris, Floyd H.

Piety, R. G.
Rice, R. B.
Tucker, R. H.

**Bethany**
Anderson, R. G.

**Boise City**
*Sparks, James W.

**Broken Arrow**
Hawkins, J. E.

**Chickasha**
*Gilleland, Kenneth R.
*Jones, Ralph M.

**Cordell**
*Carter, Norman A.

**Dewey**
Johnson, J. R.

**Duncan**
Damon, E. F.
*Neece, Neal, Jr.

**Edmond**
#Drake, Don F.
Jones, Leland W.

**Elk City**
Eubank, B. J.

**Enid**
*Braithwaite, Al
*Caldwell, Walter
Clifton, R. L.
*Fry, William C.
Hartenberger, R. A.
*Hillery, Robert R.
Muir, J. Lawrence

**Garber**
*Rosenfeld, Leonard

**Grandfield**
*Nault, Ralph Windell

**Henryetta**
*Beightol, Richard O.

**Muskogee**
*Cotter, Horace D., Jr.

**Norman**
*Gaither, Jerrell W.
#Gilliland, Robert E.
McGuckin, Glenn M.
*Minter, W. L.
Norden, John Alexander
*Rath, Otto C.
Schriever, William

**Oklahoma City**
Abbott, Wayne R.
*Anderson, George E., Jr.
*Arkle, John P., Jr.
Beebe, B. W.
Bemrose, John
Bennett, Roy F.
Bird, Wesley E., Jr.
Bleyberg, Arnold H.
*Cash, Robert Lee
Cochrane, John M.
Cody, C. C.
Cooper, Harry M.
Davis, Richard M.
*Deupree, Edwin A.
Duke, Melvin O.
Dunn, George V.
Ervin, Lynn D.
Fee, S. T.
Foster, John Robert
Garrison, Phil H.
Hadler, Harry G.
*Harbach, Robert G.
Hawes, Julian
*Hewitt, Marvin R.
*Howell, Charles L.
Kurk, Edwin H.
*Ledbetter, Charles E.
Miller, R. D.
Moore, Delmar D.
Mount, E. L.
Murphy, Boyd F.
*Peacock, Robert H.
Perry, W. B.
*Pinney, Earl T.
Ratliff, D. W.
Roane, W. H.
Roberts, Francis A.
Roberts, R. D.
Standridge, James A.
Stones, J. Eugene
Summers, G. H.
Swan, B. G.
*Sykes, Howard A.
Talley, H. C.
*Thorsen, Wm. G.
#Tuller, Burl A.
Van Nostrand, D. J.
Warren, Paul R.
Wolff, D. J.
Wood, Carroll A.

**Okmulgee**
*Busby, Julian M.

**Pauls Valley**
*Bynum, George R.
Foster, G. A.
*Wilson, George L.

**Pawhuska**
Barber, R. Curtis
*Richey, Chester Ralph, Jr.

**Ponca City**
*Barnes, Richard P.
Becker, Adrian A.
*Blake, Dale C.
Campbell, Hollis O.
*Caro, W. R.
*Cobb, Arthur T.
Crawford, John M.
*De Witte, L.
*Doty, William E. N.
Frank, Harold Roy, Sr.
Gaebe, James R.
Gaither, V. U.
Garten, Roy, J.
Godshalk, D. S.
*Goupillaud, Pierre Louis
*Harp, Richard C.
*Hrubetz, Albert
Hughes, Roland F.
*Jolliffe, Donald Charles
Jordan, C. K.
*Laing, Wm. E.
*McGlone, J. F., Jr.
Mitchell, Donald E.
Moody, Herbert H.
*Moxley, Stephen D., Jr.
*Pelton, Charles R.
#Scheffey, Paul L.
Searcy, Frank
Smith, Ben Ward
*Turner, Lewis Kelly
Vorheis, Byron
*Wakefield, H. A.
Wells, E. L.
Whitehead, Loren E.
*Wissing, Richard Donald
*Witcher, Leland G.
*Zweers, J. R.

**Proctor**
*Young, Dewey D.

**Purcell**
Lee, Claude S., Jr.

**Sand Springs**
#Copps, Daniel J. C., Jr.

**Shawnee**
Collins, Warren
Gibson, G. D.
Lukens, John P.
Myers, Walter I.
Schaeffer, Hugh C.
Smith, Delbert F.

**Southard**
*Orlich, Budd

**Stillwater**
Hurt, Walter L.

**Tulsa**
Abel, Karl W.
*Alexander, Warren A.
*Allen, Jerry
Andrews, Harry Hugh
Arnold, Tapley G.
Austin, Arthur C.
Baade, John H.
Ballou, Albert L., Jr.
Baltosser, Robert W.
Barthelmes, Albert J.
Baum, Robert
Bayer, Kenneth C.
Bayhi, Joseph F.
*Bechner, George F.
Bennett, Owen B.
Bentley-Llewellyn James
#Berg, Joseph W., Jr.
Bevan, Thomas J.
Bishop, F. L.
Blakey, Carl W.
Bonnette, Ibrey T.
Borman, Frank W.
Born, Wm. T.
Boucher, F. G.
*Bowman, D. C.
*Bowie, Duncan M.
*Boyle, Samuel Elmer, Jr.
Breck, Howard R.
Brinnon, W. B.
Broding, Robert A.
Brown, Frank E.
Brown, Henry W.
Bryan, A. B.
Buckie, Leroy Samuel, Jr.
Buffum, Charles Emery
*Burk, John William
**Butler, W. W.
Cady, Francis H.
*Campbell, E. O.
Campbell, F. F.
Canfield, Gerald Lee
Catt, James L.
#Cengiz, N. R.
*Chase, Don Eugene
Christy, Robert F.
Clark, R. C.
Clayton, Neal
#Clinton, R. M., Jr.
Clote, Thomas Anthony
Coffin, R. Clare
Collier, John J.
Connell, Joe E.
Cooper, Harvey F.
Cooper, Jack
Coryn, F. R.
Cressman, Kenneth S.
Cronin, K. Stewart
*Crossland, Edward John
#Crouse, Keith Edward, Jr.
Crump, William Wade
Crumrine, Kenneth C.
*Cunningham, Wm. J.
*Davis, David K.
Davis, D. R.
Davis, John C.
Day, Charles E.
Dimmick, Opie
*Dix, Max W.
Duller, Charles E.
Durant, C. P.
Dyk, Karl
Dzwons, George S.
Edmonson, Carl L.
Egan, Daniel G.
Eisler, Joseph D.
*Ellis, Clifton A.
Ellsworth, E. W.
Engle, A. Wendell
Erdahl, William M.
*Eshelman, Harry S.
Evans, Julian F.
*Farrell, Joseph P.
Faust, Lawrence Y.
Fearon, Robert E.
Fentem, Richard L.
Ferguson, John L.
*Ferguson, Joseph W., Jr.
Ferguson, Paul M.
Ferris, Craig
Finley, R. K.
Finn, Robert S.
Fisher, Robert B.
Franklin, John V.
*French, John D.
Friendly, Jack L.
Frossard, Robert L.
#Garduno, Andres
Garner, J. P.
Garrette, F. I.
*Garrity, T. A., Jr.
Geyer, R. L.
Gilliam, James T.
Gilmour, Andrew
Giulio, Stanley E.
Godell, John J.
*Goetz, Louis P.
Green, R. P.
Green, T. S.
Hadley, Charles F.
Hammond, J. W.
Handley, E. J.
Handley, Ed M.
Harper, James C., Jr.
Harris, D. B.
*Harlow, Robert O.
Harlton, Bruce H.
Hart, Walter S.
Hartline, Ralph E.
*Harwood, Charles R.
Hawpe, F. M.
Heap, Wm. O.
Heineck, Robert L.
Hickey, J. T.
Hidy, John H.
Hoar, Lorimer W.
*Hobart, Henry M., Jr.
*Hockaday, H. Ray
Hodgson, Roger K.
*Holland, Richard Rainey
Hollingsworth, Robert Barclay
House, A. Maxwell
Hurry, Clare N.
Hyatt, Charles Wm.
Ingalls, Philip C.
Innes, Arland I.
*Jackson, C. Kenneth
Jackson, J. G.
*Jacobson, Rollyn P.
Jameson, Chet H., Jr.
*Jenson, Arnold R.
Jett, Glendon D.
*Johnson, Donald E.
Johnson, James F.
Jolly, Richard N.
*Jones, Donald W.
*Jones, Herbert Gene
*Jones, Joe H.
Jones, V. L.
Kartman, Douglas J.
*Kaschak, George R.
*Kastner, Oscar J., Jr.
*Kehoe, Charles A.
*Kelley, William E.
*Kennedy, Howard L.
*Keselik, Joseph
Keys, Robert T., Jr.
Kezeler, J. L.
#Kidd, Donald F.
Kiess, Myron C.
#Kilbey, Thomas R.
Kittredge, F. R.
Knowles, J. G.
Kochendorfer, A. J.
Koeppel, B. W.
*Kornfeld, Joseph A.
*Kosarek, John H.
*Lahmeyer, John D.
Lamb, William C.
*Lambe, John P.
Lamkin, Woodrow W.
Lang, Harold M.

Lash, Charles C.
Lawrence, Clifton C.
Lawrence, Franklin L.
Lawrence, H. W.
Lawrence, K. M.
Lawrence Wm. P.
Laws, J. O.
Leas, Ruth Rice
Lee, Richard E.
Leedy, F. B.
#Lima, Ibsen Correia
Lynn, Ralph D.
Lyons, Paul L.
*Major, Maurice W.
Manhart, T. A.
Martner, Samuel T.
Marucheck, Joseph L.
*Massey, Oris D.
*Mathieson, Raymond L.
Maxey, J. R.
Mayes, Tom D.
McAlister, C. H.
*McAnally, Donald Edward
*McCaslin, John C.
McCollum, E. V.
McCormick, Max D.
McCracken, Guy I.
McCravey, Leroy
*McDonald, Charles R.
McKee, Clarence Richard
*McKenzie, Daniel B., Jr.
#McKeon, Edward Patrick
McManis, Louis B.
McMillen, Ralph E.
McMunn, Charles E., Jr.
McNatt, E. M.
Miller, James W.
Mills, Robert G.
Mitchell, Fielding L.
Moore, Homer C.
Morris, L. G.
*Morrisey, Norman S.
Mossman, R. W.
Moynihan, C. S.
*Naugle, Charles E.
New, James R.
Newton, George R.
*Nicholls, Harry R.
#Noble, Jack A.
Novelly, Walter O.
Oliphant, Charles W.
Owen, H. E.
Owen, John E.
Parmenter, H. R.
*Patterson, L. J.
Pelzer, H. L.
Pennington, Wallace E.
Pentecost, Claude D.
Peterson, Glen
Peterson, V. A.
Pirson, Sylvain J.
*Poe, Jack W.
Pohly, Richard A.
Pottorf, Newell
Preston, B. G.
*Putnam, Melvin E.
Rankin, C. T.
Reed, David E.
Reed, George W.
Rees, Wesley W.
Reeves, W. A.
Reid, A. C.
Richardson, H. L.
Richardson, J. W.
Ricker, Norman H.
Riendl, Joseph A.
Ries, John A.
Riggs, R. J.
Roark, James J.
Roark, James J.
*Roberts, James Everett
Roberts, Price E.
Robertson, K. A.
Robinson, W. Bernard
Roe, Edward O.
Roemer, C. D.
*Rogers, M. H.
Rollins, J. C.
Ross, Charles M.
Rummerfield, Ben F.
Rupnik, John J.
Rutledge, Richard B.
*Sanders, Raymond L.
Saubert, R. W.
Schedler, George D.
Schempf, Edward G.
Scherbatskoy, S. A.
Schmalz, Herman J.
*Schnieder, Eugene T.
Schoellhorn, S. Wm.
Scott, C. B.
Shannon, Charles W.
*Sheehy, Marshall E.
Shivers, Grover C., Jr.
Sibley, W. B.
Silverman, Daniel
*Sims, Robert L.
Smith, Cyril B.
*Smith, Edwin F., Jr.
Smith, Frank B.
*Smith, Keith E.
Smith, W. N. M.
Snow, Leland
Sorge, William A.
Southgate, Tom F.
*Spangler, A. L.
Sparks, Neil R.
*Sprinkle, Don L.
Steed, Paul H.
*Sterr, Armond L.
Stover, Edward B., Jr.
Strachan, Clyde G.
Swift, Gilbert
Sype, William R.
Taylor, Albert
Taylor, Garvin L.
*Tedder, Joseph Wall, Jr.
Thomas, Lloyd O.
Thomas, T. J.
Thomsen, Erik
Thralls, H. M.
*Tibbetts, Arnold M.
*Townsend, Kenneth S.
Tucker, Paul M.
Van Cleave, R. F.
*Van Horn, William Hart
Vernon, Jess
Von Croy, Stefan
Waddell, V. H.
*Waldrep, W. Day
Walton, George G.
*Warren, Howard B.
*Watson, A. P.
Watson, Robert J.
Weatherburn, K. R.
Weatherby, B. B.
Weichert, David R.
Weichert, Rudolph F.
Weingartner, R. A.
Weirich, P. A.
Weltsch, E. H.
Westby, G. H.
*Westphal, J. A.
Whitaker, Rayford L.
*White, Dan Gordon, Jr.
Widess, M. B.
Wilcox, Stanley W.
Williams, Jim R.
Williams, P. S.
Williams, Richard
Winnek, James R.
Woodburn, James E.
Woodward, George Morgan
*Zongker, Raymond C.

**Watonga**
*Scott, John C.
#Strozier, Robert J.

### OREGON

**Aurora**
Lester, O. C., Jr.

**Grants Pass**
*Goldenstein, S. J.

**Portland**
*Seafeldt, Concomly Albert

### PENNSYLVANIA

**Bethelehem**
Gallagher, Robert T.
#Smith, James G.

**Camp Hill**
*Dickson, James A.

**Ebensburg**
#Bender, Frederick A.

**Jeannette**
Galpin, Sidney S.

**McKeesport**
*Hartman, W. M.

**Newton Square**
Johnson, F. L.
Mayes, Fred M.

**Norwood**
Bazzoni, Charles B.

**Oakmont**
Hedberg, Hollis Dow
Smith, Douglas H.
*Whitley, Joseph M., Jr.

**Palmerton**
McMurry, Howard

**Philadelphia**
Agocs, W. B.
Jensen, Homer
*Stuart, David J.
Weeks, Albert W.
#Wylie, Robert W.

**Philipsburg**
#Mandel, Peter, Jr.

**Pittsburgh**
Affleck, James
*Alexander, Frank C., Jr.
Allen, Frank T.
Allon, Michael
Bailey, Lothrop H.
Bardeen, Thomas
Barton, Edward I.
Boardman, Dorothy Mae
*Burkemper, Robert R.
Carter, R. B.
Copeland, Douglas S.
*Darby, E. K.
*Dean, William C.
Demshar, Ludwig S.
*Duecker, John C.
Durbin, Howard A.
##Eckhardt, E. A.
Elkins, Thomas A.
Fink, Paul O.
*Frankenberger, Zdenko
*French, John Randolph
Gardner, Louis W.
Gealy, Wendell B.
Hammer, Sigmund I.
Head, E. I.
Heck, Henry W.
*Howenstein, Norman Louis
*Krivoy, Harold L.
Lugenbill, John M.
Muffly, Gary
O'Donnell, T. J.
Palmer, Alvin Paul
Palmer, Elton M.
Palmer, Loyal D.
*Pappas, Constantine Nicholas
Patnode, Homer Whitman
Peters, Leo J.
Reiser, Robert G.
**Ritzmann, O. F.
#Robinson, Enders A.
Scott, J. Lewis
*Southwick, Peter F.
Teague, M. W.
*Vitale, Robert P.
Wardell, John M., Jr.
Watson, George R.
Wickerham, W. E.
Wigbels, Frank B.
Wyckoff, Ralph D.
*Zacher, Irving C.

**Portage**
#Cervik, Joseph

**Smithton**
#Strickler, Donald

**South Williamsport**
*Wessman, Frederick H.

**State College**
#Andrews, Alday B.
#Campbell, Robert E.
Howell, B. F., Jr.
#Huber, Robert Evans
#Mathur, Surendra Pratap
#Natwick, Arrid S.
#Smith, Donald Alan
*Wyble, D. O.

**Tarentum**
#Goslin, Lewis N.

**West Pittston**
#Gill, Robert C.

**Williamsport**
Pentz, Harold H.

### RHODE ISLAND

**Gaspee Plateau**
*Gartner, Robert J.

### SOUTH CAROLINA

**North Charleston**
#Koehler, Michael J.

### SOUTH DAKOTA

**Faith**
#Glinkman, Jack V.
*Minton, Richard B.

**Mobridge**
Grosse, Will Alex

**Rapid City**
Ludwick, C. C.
*Young, T. Eugene

### TENNESSEE

**Knoxville**
*Colman, Hugh C.

**Oak Ridge**
Banta, H. E.
Garrett, Geo. A.

### TEXAS

**Abilene**
Arnold, Maurice Edgar, Jr.
*Diltz, Emory Eakman
Fuller, Roy Lee
Grange, Donald C.
*Hewitt, Jack E.
*Krejci, James F.

**Alice**
*Moss, Sam B.

**Alpine**
Bevier, Geo. M.

**Alvin**
*Hunt, Billy Dean

**Amarillo**
Kern, Jack C., Jr.
#Pool, Robert C., Jr.

**Arlington**
Mayfield, Cecil W.

**Austin**
*Adamson, W. H., Jr.
#Babcock, Walter R.
*Cartwright, Jack C.
Horton, Claude Wendell
Hughes, Darrell S.
*Lewis, Walter S., Jr.
*McLoud, R. Earl
Miller, B. R.

Reed, Charles B.
Rucker, James H.
Thomas, Earl
White, Glifford E.
*Woodward, Thomas C.

**Bandera**
Thompson, R. P.

**Beaumont**
Bills, Samuel E.
Cheesman, Thomas R.
*Christian, Fred H., Jr.
Ellis, L. G.
Evans, William T.
Gammon, Orin Rex
Guseman, L. F.
*Hagemann, R. F.
*Hastings, E. S.
Henson, Robert L.
Hollingsworth, W. E.
Hopkins, Richard H.
Jantz, O. I.
Koenig, Robert J.
Konz, Leo W.
*Lavergne, Arthur J., Jr.
McCalpin, George A.
*McIntosh, W. D.
*McKeever, Carl Daniel
*Meek, John William
Miller, Thomas F.
Millington, John W.
Moredock, John D.
Mueller, Arno P.
*Noble, Francis H.
Parker, Herbert
*Patrick, William R.
*Perkins, William R.
*Pierce, Russell, Jr.
Pratt, Ernest A.
Richert, B. E.
*Tiller, Wesley A., Jr.
Watson, Wm. A.
Weston, Horatio C.
Winterhalter, Alfred
Yeates, F. L.

**Beeville**
Claunch, E. B.
Jackson, Ralph S.

**Bellaire**
*Andrews, Robert T., Jr.
*Baker, Jerry D.
Borello, Adolfo Frank
Butler, Roy
Cowles, Laurence G.
*Crook, Troy N.
Frank, Anne R.
Guyod, Hubert
Happel, Henry H., Jr.
Herzog, Gerhard
Hibbler, Alfred J.
Hubby, L. M.
Itria, Oswald
Lee, B. D.
Manes, O. B.
McPherson, Barton F.
Nickerson, Thomas D.
*Norman, Clarence D.
*Parker, Kenneth L.
Parrack, A. L.
*Phillips, Jonathan W.
Pranglin, John A.
Quarles, Miller W., Jr.
Redding, Vernon L.
Rogers, Revill M.
Romine, William Lee
Rookus, James D.
Strain, Wm. E.
Tatsch, O. D.
Treybig, J. A.
Watzlavick, Joseph D.
Wendenburg, Otto
Woolson, John R.

**Big Lake**
*Erickson, John O.
*Scofield, Louis M.
*Shack, William Kenneth

**Big Spring**
Barnes, Chester F.
*Butts, James Y.
Dahse, Clem A.
*Kelly, John S.
*Priebe, William Joseph
*Stouse, Robert G.
Wilson, Warren A.

**Brady**
White, H. Paul

**Breckenridge**
Johnson, G. Wayne

**Brenham**
*Eckley, Wesley

**Brownfield**
*Foster, Floyd F., Jr.
Gaither, Harold L.
Holland, Taylor H.
*Kaukonen, E. K.
Keffler, Joseph W.
McReynolds, P. T.

**Brownwood**
*Teague, V. E.

**Bryan**
#Blank, H. Richard, Jr.
*Clark, Frances Allan, Sr.

**Campbell**
*St. Clair, Virgil

**Cisco**
*Porter, C. P.

**College Station**
#Andrews, Eugene R.
Dehlinger, Peter
Goedicke, Thomas R.
#Lewis, Eugene T.

**Columbus**
Etheridge, Kirby E.

**Comesa**
*Jechow, Braden W.

**Corpus Christi**
Baird, John Malcolm
Bolinger, John W.
Bychok, Victory
Coffin, Miller G.
Daugherty, C. G., Jr.
*Elms, Benjamin M.
Grizzell, Edward I.
Hoover, Lawrence E.
Howard, Ralph C.
Jewell, David F., Jr.
*Mackle, Vincent D.
Mason, C. C.
Pfenning, Walter F.
Teasley, Samuel A.
*Thompson, Norman E.
*Whaley, William J., Jr.
Wood, A. B.
Zazvorka, Jerry, Jr.

**Corsicana**
#Thompson, Wilbur L., Jr.

**Crane**
*Patch, James R.

**Dalhart**
Gullickson, W. D.
*Plumb, Paul S.
*Wellman, H. D.

**Dallas**
*Acrey, Donald O.
Agnich, Fred J.
*Albright, Ernest G., Jr.
Alcock, E. D.
Aldrich, Richard W.
Amis, Walter H., Jr.
*Anderson, Richard C.
*Anderson, Russell W.
Andrews, Reagan H.
*Angona, Frank Anthony
Arceneau, J. E.
Arnett, R. D.
Arnold, Kingsland
Ayres, Otis
*Baker, Forrest Grant
*Banks, James O., Jr.
*Banning, John A.
Bays, David Scott
Bazhaw, W. O.
Bellican, Joseph B.
Blattner, Sanford D.
*Blum, Harold Arthur
*Bogart, Bobbie Joe
Bonebrake, Walter C.
*Boone, James H., Jr.
Brantley, L. L., Jr.
*Brede, Erwin C.
Breedlove, Ruth
*Brennan, Daniel F.
Briggs, George Wendell
Brock, Fred A.
*Brouillette, Etienne
Brown, H. Hallock
Burg, Kenneth E.
#Burke, William H., Jr.
*Burrows, Hiram W., Jr.
Bussard, William H.
*Callahan, James A.
Capp, J. T.
*Carrow, James O.
Cathey, John A.
*Chadwick, Curtis Lee
*Chamberlin, C. W.
*Champlin, Jerry B. F.
Clewell, Dayton H.
Clifford, O. C., Jr.
Cline, Paul J.
Cobb, Howard L.
Coleman, Robert V., Jr.
Collingwood, D. M.
Collins, Francis, Jr.
*Collom, Alfred J.
Conant, E. E.
*Condren, Patton
Congdon, R. L.
Conklin, Glen M.
*Conroy, Richard L.
*Cooper, Jesse E.
Cornelison, Boyd
Cortes, Henry C.
*Coursey, W. Dudley
*Cundiff, Jerry A.
Dahm, Cornelius G.
Davidson, David B.
Deegan, Charles J.
*Deford, H. L.
##DeGolyer, E. L.
Deloach, E. L.
*Denn, William Joseph
Dennis, Terrence E.
Denton, D. M., Jr.
*Dixon, H. B.
Dobrin, Milton B.
Dobyns, D. R.
Donnally, Chester J.
Douglas, Norvel
*Duchscherer, Wm., Jr.
Dugan, Albert F.
*Dunagan, Lillard C.
Dunlap, Henry F.
Dunlap, Robert C., Jr.
Eastes, William T.
Edmonston, William J.
Eley, James C.
Elliott, Clinton H.
Ellsworth, T. P.
*Evans, Bobby L.
*Evans, Sam L.
Everett, R. D.
#Fagg, David B.
Farrow, B. D.
*Felber, Joe F.
*Filson, H. F.
Fisk, Frank K.
*Fjelstul, C. R.
Floyd, Roy
Foote, Lewis C.
Fordham, Glenn W.
*Fowler, Frederick B.
Frasher, James H.
*French, Francis C.
*Frick, Herbert C.
Friday, Marion T.
Frost, Holloway H.
Fuller, John Frank
Garrett, M. M.
*Garthwaite, Ivan Hiram
Gary, James W.
*Gautreaux, Jos. H.
Geer, J. T.
Giles, Benjamin F.
Gill, John D.
*Gillett, Morris Fogle
Gillin, John A.
Godbey, John K.
Godbey, Josiah Jernigan
*Godson, Richard H.
*Goodgame, Paul B.
*Graebner, Robert J.
*Graham, Leroy G.
Granberry, Harold E.
Green, Cecil H.
Green, John Wyeth
*Greene, John H.
*Gregg, Ward R.
*Griesedieck, B. H., Jr.
Griffin, W. Raymond
Griffith, Dale
Gsell, R. N.
Guipre, Robert W.
*Gunter, John R.
Haggerty, Patrick E.
*Hall, Levi Harvey
Hamm, W. Dow
Harkey, W. J.
Harkness, T. O.
*Harlan, Roger B.
*Harmon, B. F., Jr.
*Harmon, Fred
*Harris, S. T.
#Harrison, William A.
Hartley, T. R.
*Haseltine, Harvey M., Jr.
Hathaway, Milton S.
Haynes, Clifford G.
Heaps, Stanley
Hefferman, William H.
Heilner, Donald Edwin
Henderson, J. B. H.
Henkel, John H.
Herlihy, Daniel E.
Heroy, Wm. B.
Heroy, Wm. B., Jr.
Hieatt, Herbert
Hightower, C. H.
*Hill, D. E.
*Hillman, W., Jr.
*Hines, Harley Frank
Hogg, W. B.
Hollis, Jack L.
*Hollis, James T.
*Holmes, G. T.
Holmes, Odie M.
Horn, J. W.
Horn, Russell E.
Howard, George A
*Hughes, James R.
*Hughes, V. C.
*Hunt, H. B.
Imle, John F.
Isensee, George W.
Ives, Harry Crockett
Jackson, Waldo Emerson
Jasinski, J. E.
Johnson, Lloyd
*Johnston, Edward, Jr.
Jones, Hal J.
Jones, M. P.
Jonsson, J. E.
Jopling, Don W.
##Karcher, J. C.
*Kaufman, Charles S.
*Kelly, J. J.
Kelly, James Donald
Kelsey, Martin C.
Kennedy, Frank H.
Kiely, Charles M., Jr.
Kiesler, Ernest A.
Kimler, Benjamin F.
*King, V. Hugo

*Kitzman, A. C., Jr.
*Knittle, Richard J.
*Koetting, Norbert C.
*Kovelan, Edward C.
*Kraye, Robert F.
#Lamm, Robert J.
*Lamont, William Alexander
Lawrence, Philip L.
Lee, Chwan-Chang
*Lee, Ingram, II
Lester, John A.
Leventhal, Stanley M.
*Linehan, Alton L.
*Lipscomb, Earl W.
*Livermore, Howard W.
Livingston, H. Raymond
Lodge, James T.
Logue, L. L.
*Lohrentz, Donald
#Lontos, Jimmy Tom
Loper, George B.
*Loyd, Edward R., Jr.
*Luehrmann, Robert Oscar
*Luehrmann, William H.
*Luker, Robert W.
MacNaughton, Lewis W.
Marshall, H. D.
Martin, John L.
*Martin, Lucien T.
*Mayhew, Charles M.
McBurnett, Harry, Jr.
McBurney, Charles G.
McCain, Hugh, Jr.
McCarver, Holland C.
*McConnell, E. B., Jr.
McCoy, G. W.
McDermott, Eugene
McDonal, Frank Jarrett
McFadden, W. A., Jr.
McGehee, Theodore Samuel
*McGiboney, James C.
McManus, Jack V.
McMullin, E. F.
McNaughton, D. A.
*Miller, Charles M., Jr.
Miller, Jeff E., Jr.
Miller, J. W.
Milstein, Mark
Mitchell, George D., Jr.
Mitchell, W. R.
Moran, Ray O.
Morgan, Chas. Gill
*Morrison, Blackstone L.
*Mugrage, Eugene Girden
Murphy, John T., Jr.
Musgrave, Albert Wayne
Mut, Stuart C.
Myers, John R.
Napier, T. S.
Nash, David M.
Nash, Paul E.
*Neavitt, Kennard I.
*Neitzel, Edwin B.
*Nelson, Jerome Severin
Newton, W. W.
*Noble, Graves E.
Nogami, Henry H.
#Norem, Nevoy M.
*Orsinger, Albert Remington
Page, John S.
*Parrish, Jerry James
Paslay, L. C.
Patton, C. E.
Peacock, H. B.
Pellillo, M. J.
*Pennington, Dearyl E.
Pernell, J. H.
Perryman, J. D.
Petersen, Clark A.
*Peterson, James S.
Petterson, Robert W.
*Pflueger, John C.
Pittman, C. V. A.
Price, Justus V.
Prickett, Tom, Jr.
*Pritchett, William C.
Radebaugh, Robert P.
Ransom, J. H.
Ransone, W. R.
Reagor, Edward C.
Reedy, Frank, Jr.
*Reeves, James N.
Renner, Darwin S.
Rettger, Robert E.
*Rhodes, Lloyd H., II
Richards, David Carl
*Rielly, John F.
Riggs, Emmet Dean
*Rivers, James C. S.
*Roberson, Charles B.
Rogers, J. B.
Rollins, J. Frank
Roper, Wm. B.
Rosaire, E. E.
Rose, H. W.
Ruback, Norman
Rusconi, Eugene
Russell, Dallas L.
Rutherford, Charles R.
*Saliba, David J.
*Sanford, Robert E.
*Scheel, David Robert
Seiler, George E.
*Sell, Wayne E.
Sengbush, Raymond L.
Shaller, Robert B.
Shook, Earley M.
Shugart, T. R.
Shuler, Ellis W., Jr.
Simon, Randolph F.
Sistrunk, John David, Jr.
*Sledge, Thomas Collin
Smith, A. Horton, Jr.
*Smith, Bryan F.
*Smith, Harold D.
#Smith, Marwick K., Jr.
Smith, Randolph
*Sole, Lewis
Sorrells, B. J.
Spencer, Morris G.
Spiers, James C.
*Stanfield, John W.
*Steetle, David R.
Stehr, Raymond A.
*Stewart, Alexander T., Jr.
Stoutjesdyk, P. S.
Stripling, Allen A.
*Stuart, Carlton E.
Stulken, Edgar J.
*Swift, Gerald G.
*Tagg, Alden R.
*Tait, Jess Thomas
Thornton, Joseph W.
Tillman, T. H.
Toomey, Eugene J.
*Totzke, Frank D.
Towles, Henry C., Jr.
Tripp, R. Maurice
Tronrud, Roy W.
Trostle, Thomas Dale
*Tubbs, Kenneth Ray
*Underwood, Wayne L.
*Urrutia, Carlos, II
Utesch, John C.
Van Nostrand, Robert Gaige
*Vetter, Edward
*Walker, G. B.
*Walkup, William M.
Waller, J. A., Jr.
Walsh, T. N.
*Walters, C. G.
Walton, Paul L.
Warrick, Thomas R.
Weatherby, S. Preston
*Wentner, Bruce C.
Werth, Henry C.
Westmoreland, Earl E.
White, James E.
Whorton, L. P.
Williams, Floyd J.
*Williams, Ocie G.
*Williams, Ralph K.
*Willis, Ben E.
*Winn, C. L.
Wise, Henry
*Wodrich, Frank W.
Woods, J. P.
Woolley, William C.
*Worley, John Kyle, Jr.
Wuenschel, Paul C.
*Zwiebel, George Henry

**Dell City**
*Lynch, Jack

**Duncanville**
#Berry, James E.

**Edna**
Blair, John F.

**Eldorado**
*Edmiston, Billie P.

**El Paso**
#Sample, John T., Jr.

**Fabens**
Davidson, G. B.

**Feer**
*Jameson, William H.

**Ferris**
*Winn, Billy

**Ft. Stockton**
Douglas, Jas. Y.
#Siegfried, R. C.
Trostle, Maurice E.

**Ft. Worth**
Anderson, Owen William
Aszklar, Stanley J.
Baird, Walter D.
Balbin, Paul D.
*Balzer, John W.
Barnum, Warren R.
Bartel, Robert R.
*Baudoin, F. F.
*Bell, George A., Jr.
Belt, George R.
*Bledsoe, M. O.
Boatman, Richie Ellsworth
#Bond, James P.
Boring, Burl J.
Bradley, Waring
Brewer, Richard
*Buller, Leonard K.
*Childress, Kay H.
*Clendening, Charles C., Jr.
Cole, E. G.
*Conrad, Gunter, W.
Dana, R. H.
*Dayton, Morris E.
*Deaver, William W.
Divelbiss, James
Diveley, Paul R.
Dudley, Raymond W.
Fitts, Mac Elmore
Gemmill, Edward J.
*Greenfield, Clifton Orel
Gullick, Carl H.
*Haggard, Wiley R.
*Harmonson, John R.
Harrell, J. G.
Harris, Sidon
*Hartman, Frederick H.
Harvey, Castle J. C.
*Hassenfratz, C. A., Jr.
Heggblom, J. Roger
Herron, Robert C.
*Hunt, J. Richard
Itten, H. E.
Johnson, C. S.
Kebow, R. B.
Kerr, V. Robert
Klabzuba, Robert E.
Krieg, Edward A., Jr.
Laneve, R. O.
Lang, Ralph H.
*Lankton, John M.
Ledyard, Paul H.
Lee, Lynn K.
Lockhart, Gwendolyn P.
Lombardi, Leonard V.
Lovejoy, J. B.
Matthews, E. W., Jr.
Mayo, H. Bruce
McCleary, Henry C.
McCreary, Dosh T.
McDavid, P. M.
McKay, A. E.
McLemore, Ethel Ward
Mitchell, Bascom Loran
Morrill, Junis Hughes
Morris, James L.
Mortlock, Frank O.
Normand, S. R.
Payne, C. Win
Pilcher, Ned
Prokesh, Hugh E.
*Rasco, William A.
Robinson, B. B., Jr.
Rutherford, Robbie Gene
Sanders, C. W.
Schouten, F. H.
*Scoggin, Hollis A.
Seaman, L. O.
*Simmons, Cal Yates
Smith, G. N.
Strange, O. A.
*Tabor, Leon E.
*Thomas, George L.
*Thompson, H. F.
*Turman, Thomas R.
Van Steenberg, S. K.
Vastine, Thomas J.
*Ward, Charles J.
Warren, Kirby J.
Webster, John M.
Wert, Carl M.
*Wesley, Richard H.
Wilson, John H.
*Wilson, John H., II
Winter, George W.
#Wolf, Mike
Woods, Delmer M.

**Franklin**
#Sheffield, Donald Hinson

**Gainsville**
*Anneler, Joy J.

**Galveston**
*Becker, Robert C.
*Goodfellow, Robert T.
*Ramey, B. J.
*Richard, Carl R.
*Sanchez, Abelino B.
*Younger, Charles Leslie

**Garland**
*Baker, Buford M.
Oden, A. J.
Stanton, Austin N.

**Georgetown**
*Rader, William P.

**Giddings**
*Archer, Milton

**Gonzales**
*Schurig, Fred Max

**Grapevine**
Deacon, L. E.

**Hamilton**
Stiles, Elisabeth

**Harlingen**
Bratlie, Harold Swan

**Hearne**
Dodd, C. R.
*Steele, Russell E.

**Hereford**
*Herr, Wilfred C.

**Hondo**
#Dannemiller, George David

**Houston**

*Abbott, William C.
Adams, Weaver W.
Aden, James D.
Adler, Joseph L.
Akkerman, Richard Pete
Allen, Stanley R.
*Allen, William Edgar
Allen, Wm. G.
*Amery, George B.
*Ames, Richard F.
*Anderson, John C.
Anderson, John F.
Andrews, W. W.
Arnett, Richard A.
Arsenault, Charles A.
Arthur, Marion A.
Athy, L. F.
Bader, Glenn E.
*Ball, John Douglas
*Banchio, Francis J.
Barber, Thomas D.
Barbisch, Joe Bill
Barclay, Stewart
Barker, Alvin F.
Barksdale, Gerald L.
*Barman, Douglas D.
Bartow, Arthur I.
Bass, B. L.
*Bassinger, William E.
*Bearnth, Robert E.
Beeman, Keith Raymond
Beeth, C. Donald
Bell, Olin G.
Benke, M. L.
Benson, V. K.
Berg, G. A.
Berleth, W. H.
Bertram, A. C.
Bible, John L.
Bills, Robert N.
Bingham, W. W.
Bird, Ross H.
*Black, Charles W.
Black, J. P.
*Blair, Raymond Harvey
Blau, L. W.
Blevins, Paul
Bohannon, Milton A.
*Book, L. R., Jr.
Boudreaux, Edward A.
Boyd, Hiram Craig
*Branham, W. H.
Bratton, D. J.
Briard, Vernon E.
Briggs, Robert B.
Bristley, Leon P.
Britt, J. A.
*Brock, John L.
Brooks, James A.
*Brotherton, V. J.
Broussard, C. H.
Broussard, D. Frank
Brown, E. E.
Brown, Hart
*Brune, Leroy Charles
Bruyere, R. N.
#Brys, Eugene C.
Bulhon, J.
Bunsen, A. W.
Burkhalter, Howard Lee
Burkhead, Wayne Z.
*Burkman, Bill C.
Burt, W. H.
Byers, John W.
Cain, James Edward
Campbell, H. H.
Carlisle, Charles H.
Carlton, Dave P.
*Carnes, William
Carter, Ray K.
Catchings, Robert F.
*Chalker, Bruce O.
*Chalmers, F. L.
*Chapman, Wm. B.
Charrin, Paul J. D.
Charske, Charles J., Jr.
Cheney, Robert H.
Chernosky, Allen A.
Child, V. E.
*Christman, Albert J.
Clark, George B.
*Clark, Sherman D.
Clark, W. C.
Clark, W. O.
*Clements, Wallace E. R.
*Clevenger, M. A.
*Clifford, Edward Lehr
Conwill, George E.
*Cook, J. P.
Cook, Paul C.
#Coppedge, D. G.
Cornett, J. R.
Coster, H. P.
*Courtney, Cecil
Cram, Ira H.
Crary, James D.
Crowell, J. H.
*Crum, Donald L.
Culbertson, J. A.
Dauphin, W. D.
Davis, Warren L.
Delflache, A. P.
Deussen, Alexander
Dewoody, D. A.
Dexter, Laurence N.
Doe, Robert E.
*Doss, Joe
Dunaway, J. H.
#Duncan, Newton O., Jr.
Dupont, T. F., Jr.
Dupree, Leon L., Jr.
Durapau, Joseph J.
Duty, Robert S., Jr.
*Duval, Ned E., Jr.
Eby, J. Brian
*Edwards, Charles E.
Ehrharot, Henry L.
*Ellison, Charles E.
Elms, Roger G.
England, C. M.
Evans, E. P.
Farren, Paul
*Faudry, Ray E.
Fay, Charles H.
Feagin, Frank J.
*Feather, J. E.
Feather, W. R.
*Fegan, George K.
Ferguson, J. B.
Ferguson, Joe L.
Fielder, Cecil K.
*Finnegan, Michael J.
Fish, Robert Dudley
Fishback, Joseph W.
Flatow, Tobias
Fleischmann, C. S.
Flude, John W.
Flynn, B. Michael, Jr.
Fohs, F. Julius
*Foote, W. L.
*Francis, W. Douglas
Freel, J. F.
Fritts, G. E.
*Froelich, James E., Jr.
Frosch, Alex
Frowe, Eugene
*Fryer, Alan P.
Gallaway, R. L.
*Ganek, Bruce M.
Gardner, Derry H.
Garrett, Wm. W.
*Garrod, Thomas A.
*Germany, Clinton Benford
Gerrard, J. A. F.
Geyer, Richard A.
*Gibbons, William Dean
Gibson, Wm. H.
Giezendanner, Stuart S.
Gilbert, Gerald G.
Gilbert, Howard J.
Giles, Howard Windfield
Gill, O. P.
*Girard, Harry J.
Glenn, E. J.
Goldstone, Frank
*Gorman, D. Y.
Goss, Henry V.
*Grafton, W. Dean
Graham, John R., Jr.
Green, W. G.
Griffin, Irving M., Jr.
*Guiler, Mona D.
*Hackenberg, Charles D.
Hafner, W.
Hagen, Cecil
*Hajovsky, Henry J.
Hale, E. M.
Hale, R. B.
Hall, O. W.
Hall, T. O.
Hamil, A. B.
Hamill, Robert M.
Hamilton, W. Brooke
*Hammial, Leroy L.
*Hanahen, P. M.
Hans, Edward Walter
Happel, Henry H.
*Harbaugh, Allan W.
*Harding, Norman
Harkins, Curtis P.
Harkins, T. I.
Harper, William Earl
Harrington, G., Jr.
Hartman, Jack T.
Hatcher, Stanley A.
Hawes, W. S.
Haynes, R. B., Jr.
Hebert, Harold C.
*Hegar, Daniel Theodore
Heggy, Homer L.
Heintz, Karl O.
Hemmi, C. W.
Henderson, Homer I.
Hendrickson, Frank V.
Hermont, Alfred J.
*Hess, Edith May
*Hessi, William R., Jr.
*Heying, Lorence J.
Hibbler, M. E.
Hill, E. Bruce
Hill, Joseph Weldon
Hinson, Cecil C.
Hoard, J. O.
*Hobbs, Willis Ezra
Hocker, Otis B.
Hoeninghaus, F. A., Jr.
*Hofacket, Owen Leon
Hohlt, Richard Bozman
*Holland, Edward H.
Holland, Sam B.
Holmberg, Jean M.
Hoover, H. L.
Hoover, J. W.
*Hope, Ray J.
Horvitz, Leo
Howard, Ben R.
*Howe, Paul E.
Howell, Lynn G.
Hubbard, Charles L.
Hubbert, M. King
Hubner, Bernard G., Sr.
Hudman, Vernon C.
Hudson, James Davidson
*Huffman, Charles H.
Hull, J. W.
*Hume, Ernest H.
Hunzicker, A. A.
Hurt, Worth B.
Hutchinson, C. C.
Ivy, John S.
Jackson, G. L.
Jett, J. E.
*Johnson, Dean
*Johnson, James H.
*Johnson, Marn M.
Johnson, W. D.
Jones, E. E.
Jubran, Joseph R.
Judson, Sidney A.
Kannenstine, Fabian M.
*Karlskind, Don B.
Kaufman, Sidney
Keeling, Richard Wilson
Keese, James D.
Kemeny, Daniel J.
*Kemp, Robert Eugene
Kendall, John M.
Kennedy, Robert P.
Kenney, Teddy R.
Kent, Leon A.
*Kepner, Thomas Henry
Kimes, Albert
Kisler, Floyd
Klaveness, Alf
*Knight, Joseph C.
Knouse, Anthony M.
Kohler, A.
Kokesh, F. P.
*Koppel, David G.
Kouri, Barton H.
*Kovar, Merle David
Krause, Fred W.
Kriegel, H. C.
Kubik, Kasmier D.
Kunkel, Turner L.
Ladner, A. L.
*La Greca, S. A.
Lamb, Geo. B.
Larue, J. E.
Lau, Frank W.
*Lavender, Gerald J.
Lawhorn, O. T.
*Layton, Wiley Fred, Jr.
Lea, N. J.
Lea, W. T.
*Lee, Thomas S.
Lee, Walter B., Jr.
Leonardon, Eugene G.
Lewis, Ray C.
Lewis, Wendell L.
Lipson, Leonard B.
Locke, Edgar R.
Long, Gebhard J.
Love, Kenneth E.
Lovett, Don G.
*Lundstrom, Fred L.
*Lynch, Vance Milton
Lytle, T. M.
MacAllister, C. T.
Mace, G. M., Jr.
*Malicoat, William Marcel
Malone, Edwin A.
*Mann, Horace M.
Mann, Ralph W.
Mannes, W. H.
Marr, John D.
Marsh, Albert P.
Marti, E. J.
Martin, E. C.
Martin, Sidney A., Jr.
Martyn, Phil F.
Mather, W. Scott
McDowell, A. N.
McCann, K. G.
McClure, C. E.
McCollum, Burton
*McCubbin, Roy H.
*McCullagh, John, Jr.
McDonnold, H. W.
*McDuff, Milton A.
McElree, George D., Jr.
McFerron, George I.
McGee, John E.
McGowan, F. H.
McKelvy, W. H.
McLoad, Kenneth W.
*McNeill, Walter A.
McReynolds, Gregg F.
*McWilliams, Donald G.
Melchior, Louis F.
Melton, D. P.

Miller, Arthur Barrett, Jr.
*Miller, L. Ray
*Miller, Thomas J.
Millet, M. J.
*Mitchell, Robert L.
*Mogg, George Greer
Monkhouse, John R.
Montgomery, George P., Jr.
Montgomery, J. C.
*Moore, John H.
Moore, R. R.
Morris, H. B.
*Morrison, Clarence O.
Mott-Smith, L. M.
Mounce, W. D.
Mower, L. K.
*Murphy, Robert E., Jr.
*Murray, Edward F., Jr.
Murrell, James T.
Nance, A. G.
Neff, W. D.
Nelson, James K.
*Nelson, Jerry
Nelson, William P.
Nettleton, Lewis L.
Newby, C. J.
Newton, William H.
Nichols, James B.
Nicolai, Fred Henry
Nixon, Robert F.
Noonan, W. G., Jr.
*Nordling, Robert W., Jr.
*Norman, Isaac W.
*Norman, Robert
Nutt, Willard Thomas
#Olson, Alfred D.
Olson, Robert W.
Ording, J. R.
Ostreim, Russell N.
Ott, Lawrence N.
*Outcalt, Earl E.
*Pace, James R.
Paitson, Loyd
Palmer, Robert L.
Parker, L. A.
Parker, Richard H.
Parsons, Grant C.
Paschall, John P.
Patrick, Homer G.
*Paul, Kenneth E.
Pawley, Julian K.
Pechacek, Emil F.
Pemberton, William Dwight
Pena, Sam M.
*Pervinsek, Robert J.
Phelps, Kenneth D.
*Phillips, Mary S.
Pierson, Andrew Luke, III
*Pike, Harold A., Jr.
Pittman, R. R.
*Pitts, J. B.
Pitts, J. J.
Poindexter, Louis M.
*Poland, V. K.
Pollard, J. C.
Pollard, William
Pollet, Arthur
Pope, Thomas T., Jr.
*Popp, Frederick Wm., Jr.
Postma, G. W.
Powell, Paul B.
*Prator, Miles D., Jr.
Prescott, H. R.
Pruitt, M. F.
*Pugh, August Leo
Rabensburg, Aubrey H.
Randolph, James R.
Ratliff, Guy M.
Ray, Robert H.
Reed, Chas F.
Reid, William, Jr.
*Reilly, Lawrence E.
*Reinhardt, Alvin C.
*Reivere, Romaine
Reynolds, F. F.
Rhodes, Joseph Stockton
*Rice, Paul
Richards, George Leroy
*Rieker, William J., Jr.
*Riley, James K., Jr.
*Robinson, Edwin H.
Rockwell, G. O.
Rogers, Austin S.
Rogers, L. Brann
Rogers, Sam D.
Rolshausen, F. W.
Romberg, Frederick E.
Roos, Lewis V. S.
Rulfs, G. W., Jr.
Ruska, Walter E. A.
Rust, W. M., Jr.
Sagoci, Hilmi F.
St. Germain, R. J.
*Sanders, George
Sappington, Chester
Sargent, R. L.
Sasseen, John H.
*Sawyer, Halbert
*Sax, William A.
Schafer, Sidney
Schander, Johannes R.
Schmidt, Henry
Schmuck, R. H.
*Schneider, J. W.
Schofield, G. A.
Scott, David H.
*Scroggs, James E., Jr.
Schumacher, J. P.
Sears, Harold A.
Segal, Jerome Joe
Selig, A. L.
Sellers, Blake M.
Sellers, Charles C., Jr.
Sellers, Clemille Franklin
Sheets, Martin M.
*Shera, Frank White
Sherar, E. S.
Sherar, Stuart
Shimek, E. Joe
Shore, Harold F.
*Showalter, Richard C.
*Sims, Sam E.
Sisson, Harry H.
Smith, A. E.
Smith, Aylwin L.
*Smith, Donald Raymond
Smith, George R.
*Smith, Harold B.
Smith, H. C.
Smith, Neal J.
Smith, Noyes D.
Smith, Roy O.
*Smith, Stewart W.
Somers, George B.
*Spadachene, Anthony
*Speckels, Arthur W.
Spencer, Jean S.
Spencer, Samuel A.
*Stallings, Billy M.
*Stanford, Earl Brock
Stanley, Leycester
Stauffer, Arthur L.
Steele, Wm. E., Jr.
Steenland, Nelson C.
*Stephens, Lester H.
Stewart, S. B.
Stommel, H. E.
Stone, George B.
Stratton, Everett F.
*Summers, Frank Bailey
Swanson, Marion T.
Sweet, R. C.
*Talmage, F. W.
Taylor, Josiah
Taylor, W. H.
Teague, Norman P.
Terrasson, Paul Louis P.
Terry, Melvin C.
Terry, Russell D.
Thackston, Warren C., Jr.
Thomas, Dick L.
Thompson, Jay F.
Thompson, Kermitt C.
Thompson, Paul M.
Thompson, R. R.
Todd, James H.
Tucker, Robert L., Jr.
Turner, George R.
Turney, Maurice D.
Tweddell, Ralph D.
*Urban, L. M.
#Urquhart, Edward H.
Van Auken, John A.
Vanderdoes, George Glenn
*Van Dusen, M. D.
Van Melle, F. A.
Van Siclen, DeWitt C.
*Veasow, Jack H.
*Venters, John Bowden
Vernon, George H.
Vogel, Charles B.
Vreugde, L. M. H.
Vreugde, Th. L. J.
Wahl, Carl C.
Walker, James E.
Wallace, C. R.
Wallace, F. Ritchie
Wallace, James L.
Watt, J. S.
Weaver, Paul
Webb, Kenneth
*Weber, John D.
Welboan, J. S., Jr.
*Welch, Margaret Marie
*Wendenburg, Clarence F.
*Weston, Ray Franklin
*Weyand, Jack C.
*Whitcomb, Harry S., Jr.
White, Gale
White, S. A.
*Whitten, Stephen E.
Wier, Joe R.
Wilber, Roscoe C., Jr.
Wilcoxon, Robert B.
Wilkens, Lucian Minor
Williams, C. E.
Williams, E. Darrell
*Willis, David G.
Wilson, James M.
Winston, Val G.
Wolf, Alexander
#Wood, John D.
*Woodham, Billie A.
Worden, Sam P.
*Wottlin, William O.
Wright, Fred E.
Wright, James F.
Wright, Ray H.
Yokubaitis, A. C.
Zagst, Edward F.
Zenor, H. M.
Zimmerman, C. C
Zirbel, N. N.

**Irving**
Batson, James B.
*Campbell, William M.
Carson, Roe W.
Swafford, Thomas W., Jr.

**Jacksonville**
*Ragsdale, Dixie M.

**Kenedy**
*Kay, R. E.

**Kermit**
Baer, Karl E.
Smith, Edward E., Jr.

**Kingsville**
*Cross, James Harvey
Dillon, Bart J.
*Glazener, George S.
Hunt, E. W.
Starr, A. G.

**Lamesa**
Moore, Robert L.
*Norris, C. G.
*Scott, Clarence E.
*Seim, Carl Henry
Shamblin, W. E.
*Talkington, Gerald E.
Wigley, Lawrence H.

**Laredo**
*Goddard, Douglas D.

**Leona**
*Thompson, Jack Hugh

**Liberty**
*McDonald, William R.

**Littlefield**
Forbes, C. B.

**Lockhart**
*Bernard, Curtis R.

**Lockney**
Thomas, Virgil O.

**Lubbock**
Ebert, Charles E.
*Gregston, G. D.
*Hughes, John C.
Kilborn, Joseph M.
*Kilborn, Nannette D.
Klaus, H.
Logan, W. B.
Morrison, Malcolm S.
*Moss, Clellen G.
Novotny, J. D.
*Rettig, Albert Ephel-dred
Richardson, H. K.
#Scudday, Edwin R.
Smith, C. C.
*Valder, Clayton S., Jr.

**Marfa**
*Dawson, Gilbert E.

**McAllen**
Harris, B. A.
Moore, F. A.
Salisbury, Thomas R.
*Weyer, John F.

**McCamey**
*Arnold, Lee Kingston

**McQueeney**
#Haines, C. E.

**Meridian**
*Yelken, Jack Herbert

**Midland**
Arick, Millard B.
Armstrong, John Moore
Baile, Richard A.
Bailey, J. J.
*Barker, Addison S.
Barnes, A. L.
*Beard, John G.
*Blakeman, Edmund R.
*Bollheimer, Paul Andrew
Borys, Edmund
*Broyles, Robert W.
Burton, Raiford H.
*Chronister, Bill W.
*Compton, Lee
Conover, George E.
Cornell, Russell B.
Cornish, Lou G.
Daly, John W.
Dawson, L. Decker, Jr.
DeJournette, R. D., Jr.
*Dial, James B.
Digiulio, Fred J.
*Domenico, S. Norman
*Drachenberg, William A.
*Edwards, Jack W.
*Elliott, Charles Harvey
Epperson, Louis J.
Feather, V. G.
Fickinger, Elwood E.
Fischer, Leon

Fisher, Guy W.
*Foster, Aaron F.
*Gaines, Betty
Gibson, George R.
*Gilbert, Kennis W.
Goodenow, Wayne B.
Grimm, G. A.
Hake, Stanley L.
Hammel, Warren R.
*Hanna, Ian B.
*Hardison, Stanley G.
*Heidt, Arnold, Jr.
Hinton, B. H.
*Holt, Thomas C.
Homan, W. L.
Horton, J. D.
*Hovey, Gene D.
Ittner, Frank
*Ivey, James R., Jr.
Jackson, O. B.
Jasper, Walter E.
Johnson, Billy C.
Johnson, Lester H.
*Jones, Stuart A.
Jordan, Eaton A.
Kangas, Reino
Knock, Malcolm A.
Knott, Robert J.
Lago, Nils
Lawson, Royce E., Jr.
Martin, G. W.
Mason, Marshall Lee, Jr.
McFarlane, John F.
*McKinley, James C.
Mehringer, A. P.
Michaelson, L. H.
Mims, Robert L.
Moore, Arthur A., Jr.
Morehead, Jack N.
*Neill, Everett D.
*Noble, Hubert J.
Nugent, R. M.
O'Brien, William R.
Owings, B. F., Jr.
Ownby, Byron G.
Page, C. Newton
Park, Lee B.
Park, Noel Robertson
Partridge, Chester R.
Patterson, Harold F.
Peacock, Elwin M.
*Percy, C. G.
Pluta, Joseph S.
Porter, James C.
Rainey, Richard H.
Ray, Lilburn B.
Reed, Paul C.
Reel, Cecil E.
Ross, W. T.
Rumsey, Paul T.
Rustamier, Jack W.
St. Clair, Donald W.
*Schubert, Raymond Donald
Seal, W. A., Jr.
*Shettle, George O.
Shock, Lorenz I.
Shoup, George Joseph
Singer, Robert R.
Smith, William O.
*Sorgenfrei, D. C.
Stone, Robert C.
*Swanson, Jack C.
Swords, H. L.
*Thompson, Roy W.
*Tift, S. W.
#Troseth, Frank P.
Turner, Dale E.
Uhrig, Leonard F.
Unger, E. E.
Voelker, H. L.
Walker, Wm. N.
Ward, Joe H. E.
Warren, R. P.
*Welcker, Fred
Wells, R. G.
West, James L., Jr.
Winter, Niles B.
Woods, Douglas James
*Wright, Jesse W., Jr.
Wright, Randolph E.

**Mineral Wells**
*Huff, Allan L.

**Monahans**
*Newman, Canrad E.

**Mt. Pleasant**
Roesch, Robert C.

**Normanna**
#McMurry, Melville B.

**Odessa**
Bugby, Roger A.
Davis, L. A.
*Heil, Charles Grant
Johnson, William H.
*Mardirosian, Azad
*Mickelson Kermont B.
Thurber, Charles H.
Walling, F. Rex, Jr.

**Orange**
*Ard, William M.
Autrey, Charles B.
*Hargest, Thomas Sewell, III
*Hartin, Curtis L.
*Kvasnicka, Albert F.
Marlin, John L., Jr.
Maureira, Artemio S.

**Ozona**
Clement, Alvin H.

**Palacios**
Kale, Henry W.
*Littlefield, Broadus Edgar, Jr.

**Palestine**
Burney, William Morrow, Jr.
*Parker, Marion Hamlett
*Newton, Robert A.

**Paris**
*Green, Charles Wheeler

**Pasadena**
Stafford, John A.

**Pecos**
*Dick, Charles W
Opitz, E. E.
*Toliver, Billie A.

**Perryton**
Clark, K. M., Jr.
*Harvill, Robert S., Jr.
*Ingels, C. Robert
*Meyer, Robert S.
*Nicholson, Ralph C., Jr.
*O'Connor, Michael James
Thomas, Phil Howard

**Raymondville**
Ehlert, Gilbert W.
*McKinley, Wm. D.

**Riverside**
Weinzierl, John F.

**Rosenberg**
Myers, Charles E.
Neese, U. E.

**San Angelo**
*Beesley, Stratton W.
*Clemens, Augustus D.
*Green, Howard W.
Rabensburg, N. J., Jr.
*Slover, John D.

**San Antonio**
Allen, Thomas L.
*Bell, Clifford O.
Bennett, Elwin
Bissett, Clark E.
*Burkett, Ransom L., Jr.
Cook, John C.
Crawford, Paul D.
Crawford, Weldon L.
Dawson, Herbert M.
*Descher, Anton H.
*Dinkins, H. H., Jr.
Donnelly, V. T.
*Downs, J. W.
Edmonson, J. W. E.
Frazier, Dillon Schadt
#Fritz, Joseph F.
Gragnon, Joseph N.
Hannum, Wm. L.
Hargis, A. V.
Hazelrigg, James B.
*Howell, John L.
Hunzicker, Vernon J.
Kelley, Ward W.
Koenning, Eddie Lee
Langford, Eldon W.
*Langwell, August, III
McClellan, Oliver
*Moody, James L.
Moore, Marion J.
Moore, W. Lee, Jr.
Narvarte, P. E.
Ohman, John
Parr, J. O., Jr.
Petty, Dabney E.
Petty, O. Scott
Petty, Van A., Jr.
Phillips, Clifton
Pratt, R. B.
#Proctor, John L.
Rudolph, P. J.
*Russell, James C., Jr.
Schmidt, K. H., Jr.
Smyrl, H. B.
Snyder, Charles W.
Souther, J. B.
Stephenson, Lawton Blaine
West, Thomas S.
Wright, J. Dexter

**Sealy**
*Felcman, Frank L.

**Seguin**
Blumberg, Roland K.

**Seminole**
*Blackwell, J. A., Jr.
*Gilchrist, William H., Jr.
Hamilton, J. Brooke, Jr.
Henkhaus, Driscoll A.
*Heydon, D. F.
*Matson, Don D.
*Smith, Billy G.

**Sherman**
*Robertson, Glenn
Schiflett, H. L.
*Smith, Howard Leonard
*Wu, Chang Sheng

**Sinton**
*Agerton, William D.
Larue, Wilton W.
*Ramzinsky, G. D.
Stacy, E. L.

**Slaton**
*Heard, James R.

**Sonora**
Viterbo, Verne D., Jr.

**Sweetwater**
*Bralley, James M.
Faubion, Charles G.

**Turnersville**
Foote, Richard Quentin

**Tyler**
Brooks, O. D.
Flowers, Jack J.
Graham, Robert C.
Hadaway, W. R.
Hilton, Richard C.
Mataya, Jack L.
Moore, D. B.
*Morgan, Henry W.
Samford, Mack
*Wahlers, S. W.

**Uvalde**
Scott, M. D.
Watts, Evan

**Vernon**
*Jones, Ralph H.

**Victoria**
Lemaster, R. R.

**Vidor**
Stokely, Paul W.

**Waxahachie**
Shackelford, Lewis L., Jr.

**Wharton**
*Brown, Robert L.

**Wichita Falls**
Becker, Clarence Wilbur
Bradley, Joe R., Jr.
Burchett, Charles T., Jr.
Crain, R. A.
Gilmore, John A.
Guntharp, John H.
*Harris, Alfred H., Jr.
Harvey, William P.
Mayfield, W. I.
McReynolds, Oliver B., Jr.
Mitcham, Frank M.
Reynolds, E. E.
Travis, Lloyd R., Jr.
Warren, Kenneth A.
Weeth, Chas. A.
Whitney, Vernon E.

**Woodville**
O'Brien, S. D.

**Yoakum**
*Adams, Hugh M., Jr.
Autrey, D. W.
Hall, Frederic C.
Love, Perry R.
*Pettus, William F.
*Spence, H. C., Jr.

## UTAH

**Bountiful**
*Mabey, Don Russell

**Cedar City**
O'Toole, W. L., Jr.

**Gunnison**
#Frischknecht, Frank

**Loa**
*Brown, Jackson W.

**Moab**
Ashby, Julian C.

**Orem**
*Hansen, Don A.

**Roosevelt**
*Venker, Donald P.

**Salt Lake City**
*Bean, Robert J.
#Confer, Howard Lee
Cheney, John Robert
Cook, Kenneth L.
#Dolan, William M.
Earl, John H.
*Ervin, James W.
#Erwin, John W.
#Forbes, John K.
Harris, Glenn R.
Hobbs, T. E.
#Johnson, John B., Jr.
#Kim, Daniel Yon-Su
Lacy, R. J.
Marquardt, Carlton M.
*Morris, Edward W.
#Newsom, Donald Richard
Peterson, V. E.
*Price, Charles E., Jr.
Quigley, M. Darwin
#Resler, Ray C.
*Saegart, William E.
*Sims, Jesse O.
#Smith, Paul G.
*Trepagnier, Harold J.
*Whipple, R. W.

**Vernal**
*Green, James Edgar
*Roper, Donald W.

## VIRGINIA

**Alexandria**
Bowsky, Merl C.

Matthews, Richard H.
Smitherman, Lynn A.

**Arlington**
*Johnson, Robert W., Jr.
Kaiser, Geo. B.
Prade, Nat H.

**Mineral**
Smith, A. R.

**Norfolk**
*Moore, L. E.

### WASHINGTON

**Seattle**
*Bowlby, Clarence W.
*Foster, Robert J.
Hall, Robert A.
*Ostenso, Ned A.
West, S. Stewart

### WEST VIRGINIA

**Princeton**
Straley, H. W., III

### WISCONSIN

**Black River Falls**
*Trask, A. Hugh

**Gile**
♯Machesky, Lawrence F.

**Madison**
♯Mack, John W., Jr.
♯Meyer, Robert P.
♯Rose, John C.
*Sumner, J. S.
♯Thiel, Edward
♯Weart, Wendell Duane
Woollard, George P.

**Milwaukee**
♯Chenoweth, William C.

**Oshkosh**
♯Hinze, William J.

**Racine**
*Jensen, James J.

### WYOMING

**Casper**
*Benson, Albert E.
Bone, Robert M.
Brooks, W. T.
♯Brow, Leroy Edwin
Brumbaugh, Eugene R.
♯Chase, Mrs. Gordon W.
*Clark, Edward Cornell
*Cottle, Elwood M.
Dodson, Herbert F.
Early, Paul M.
Ellis, George L.
*Erickson, John W.
*Farmer, Wesley N.
Faust, S. R., Jr.
Fenwick, Willis H.
*Ferree, C. M.
*Fletcher, Calvin D.
Hawkes, Wendall H.
Hawthorne, W. W.
Heim, Jean W.
*Heine, Gordon T.
*Higgins, Robert L.
Hopkins, James S.
*Horino, Frank George
Jennings, Bruce M., Jr.
*Koch, Barry Walter
*Lake, Charles L.
Larguier, Leonard J.
Lechtenberg, W. F., Jr.
McGrady, Dupree
McKeever, J. H.
Meade, George N.
*Medlock, Ray
*Nelson, Robert L.
*O'Leary, Timothy D.
Parke, Morton L., Jr.
Partridge, John F., Jr.
*Pauly, Harold P.
Ralph, Pierson M.
Roberts, Grant M.
Roberts, Homer E.
Sawyer, Noah G., Jr.
Shell, G. Newman
*Smith, Wendell R.
Spalding, Carlton T.
*Templeton, James H.
Terry, Paul V.
*Wagner, Richard L.
Walczak, Michael J.
*Wells, William E.
*Whitaker, Richard Owen
Willis, Howard A.
Wilson, George Lee
Wilson, Thomas C.
Winfrey, D. B.

**Cheyenne**
♯Brown, David L.
*Kvenvolden, Keith A.
*Yuzbick, R. J.

**Douglas**
Hastings, James Isaac
Murphree, Harold F.

**Dubois**
*Brogden, William I., Jr.

**Gillette**
Massie, Cliff H.
*Nigh, Clarence R.

**Guernsey**
♯Hollingsworth, James C.
♯Seward, Franklin A., Jr.

**Lander**
*Healy, John C.
*Peacock, H. E.

**Laramie**
♯Anderson, William Joseph
*Opland, Homer N.
*Plott, William B.
*Romney, Carl F.
*Stephens, Ernest, Jr.
*Withstandley, Victor, III

**Lusk**
Stafford, C. J.

**Mills**
*Brown, C. Milan

**Newcastle**
Martens, Willis P.

**Rawlins**
*Basye, Edward R.
*Brown, Roger L., Jr.
Dallison, Sam James
*Gates, George Donald
*Houston, Grafton, Jr.
Johnston, Frank M.
*Mount, Thomas M.
Riess, Malcolm

**Riverton**
*Blaire, Donal H.
*Doty, J. R.
*Eitzman, E. T.
*Henning, David L.
*Tackenberg, Pieter
*Wilson, Donald E.

**Rock Springs**
*Horn, Wilbur M.
*McCuistion, Robert G.

**Thermopolis**
*House, H. M.

**Worland**
*Dreves, Jay B.
Jackson, Rodney W.
*Roripaugh, Chas. C., Jr.
Rupert, James W., Jr.
*Walz, Harry B.

### ALASKA

**Barrow**
*Brewer, Max Clifton

### ALGERIA

**Alger**
Beer, Fritz R.
*Cholet, Jacques
Ortynski, H. I.
*Van Not, Gonzales

### ANGLO-EGYPTIAN SUDAN

**Khartoum**
Makowiecki, L. Z.

### ARGENTINA

**Bahia Blanca**
Tognon, Juan Francisco

**Buenos Aires**
Binetti, Vincente
Munoz, Noble
*Murut, Aldo Raul
Orellana, E. I.
Vila, Fernando

**Ciudad Eva Peron**
*Trejo, Cesar Anselmo

**Haedo**
Rey, Pedro

**Mendoza**
*Buttini, Bernardino E.

**Neuquen**
*Fernandez, Gonzalo

**Rivadavia**
Cesanelli, Metello

**Rosario (Santa Fe)**
*Gurmendi, Juan C.

**Vicente Lopez**
Berros, Salvador A.

### AUSTRALIA

**Canberra**
Smellie, Donald W.

**Melbourne**
*De Grott, Raymond J. P.
Sauve, N. B.
Thyer, Robert F.
Vale, K. R.
Wood, F. W.

**New South Wales**
Marshall, C. E.

**Perth**
*Garrett, Maxwell James
*Stanley, Donald James
Strutzel, Lewis D.

**Sydney**
♯Rao, Veeraghanta Bhaskara

**Warrandyke**
Dooley, J. C.

**West Brunswick**
*Smith, Edward Robert

### AUSTRIA

**Leoben**
♯Schubert, Hermann

**Salzburg**
Kunz, Bruno, F. J.

### BELGIAN CONGO

**Bukavu**
*De Bremaecker, J. C.

### BELGIUM

**Bruxelles**
Brognon, G.
Evrard, Pierre

### BOLIVIA

**La paz**
*Ramirez, Andres B.

### BORNEO

**State of Brunei**
Romeijn, Cornelis
Schut, R. H. T.

### BRAZIL

**Belem**
*Koch, Herman J.
Nery, Raymundo
Stair, Robert Y.

**Natal**
*Birge, George J.
*Ducas, J. G.
Gilbert, Erle W.
Mota, Lindonor
Rusch, Peter, J.

**Rio de Janeiro**
Eichelberger, A. M., Jr.
Long, James A.
Oddone, D. S.

**Sao Luiz**
*Floyd, Fernando

**Sao Paulo**
*Arroyo, Albino

**Salvador**
♯Bisol, Decio Luiz
Martin, Rodolfo
*Van Der Gracht, William W.

### BRITISH WEST INDIES

**Trinidad**
*Baxendale, L. R.
*Geldart, L. P.
Harvey, A. G.
Higgins, G. E.
*Levorsen, Robert I.
MacMillan, John A.
Mett, Dennis R.
Nock, John R.
Northwood, E. J.
Rivers, Henry F., Jr.
Seabrooke, David S.
*Woo, Desmond A. A.

### CANADA

#### Alberta

**Calgary**
Acheson, C. Harold
*Agnew, Hinds
Alvey, G. C.
Anderson, W. M.
*Armstrong, A. C.
Armstrong, John A.
*Axford, D. W.
Aydin, M.
Babb, John J.
*Badgley, Peter C.
Baillie, Wilfred
Baker, Malcolm E.
Bannister, William E.
Barron, James
Baxter, John C.
Bearden, Carl D.
Beck, August F.
Bediz, Pertev I.
Bickel, Harold C.
Bigelow, Donald V.
*Blakely, W. E.
*Blatt, H. E.
*Blayney, Alan J.
Blundun, George J.
*Boss, F. E.
Boulware, Robert A.
Bowden, J. W.
Brannian, Ross E.
Brooks, Robert H.
Brotherhood, G. Roy
*Brown, Robert Scott
*Bruce, B. C.
Burns, Jerome L.
Bush, James H.
Campbell, Everett L.
Campbell, T. A.
*Cane, Lionel G.
*Carlyle, Robert Harold
Chesher, C. E.
*Chilton, Wm. E.
Christie, Norman J.
Clark, Donald R.
*Clark, Earl
*Comer, R. L.
*Cook, Eugene T.
Coote, George F.
Copeland, R. J.
Cox, Harris
Davis, Rollin E.
Deabler, George

Denton, Eric R.
Desmond, J. M.
Dunlap, Albert D.
*Elias, William H.
Ellsworth, Frank
*Engman, Henry E.
Erickson, E. L.
*Evans, Hugh, Jr.
Farmilo, Alfred W.
*Farrell, Patrick J.
*Ferrell, George Douglas
Fickinger, Dale E.
*Frankovitch, C. Jerrold
Freeburg, John J., Jr.
Fuller, John C. J.
*Gacek, Walter Frank
Gallacher, John D.
Galloway, John O.
Gardner, J. W.
Germond, Kenneth W.
*Goldfarb, Lionel J. B.
*Gray, Gordon L.
Gray, Henry Douglas
Green, Thom. H.
*Grinsfelder, Donald
*Gross, Richard N.
Halbrook, T. A.
Hale, Francis A.
Hale, John D.
*Hamilton, J. J. S.
Hannon, N. M., Jr.
Harding, R. N.
Hart, Corby L.
Haun, Glen Robbie
*Heaton, George R.
*Herbert, Edward Vernon
Hess, Gordon R.
*Hickey, Francis Lawrence
Hinson, James Milton
*Hobman, Richard John
Hobson, George D.
♯Hoffman, Elvin M.
Hohag, Walton H., Jr.
Holland R. D.
*Horne, David J.
Houghton, H. M.
Ingall, Lindsay N.
Irwin, W. L.
*Jensen, Arthur
Johns, N. W.
*Jones, Norman Richard
Junger, Arne
*Kanasewich, Ernest R.
Kaplan, Gerald S.
*Keefe, J. A. C.
Kidder, Harold J.
Kinsley, E. R.
*Knox, William A.
*Kunigiskis, John
Lamon, Robert S.
Legge, J. A., Jr.
Lerm, Gunter
Lipsett, Earl
*Little, J. H.
Lockwood, R. P.
*Loring, Ralph C.
*Lundy, Barry R., Jr.
*MacDonald, D. A.
*Mackay, Ian H.
*MacLean, Lachlan
MacMillan, John Kenneth
Macon, Curtis E.
Mahannah, R. S.
Maliphant, H. C.
*Manchee, E. B.
Martina, B. A.
Matthews, W. A.
*Maw, Robert Gordon
*Maxey, William A.
*Mayfield, Ira C., Jr.
*McCaffrey, Richard J.
*McColl, H. Stuart
McConnell, Fredrick Charles
*McCormack, Harold R.
*McDade, George Harold
McDougall, Donald B.
McGrew, Harry J.
*McKay, Donald A.
McKee, Alexander H.
*McKenzie, Hazel Beatrice
McKinnon, F. A.
McKinsey, M. H.
Meadours, James B.
*Merkley, J. A.
*Merritt, Robert Keith
Miller, Nash H.
Milton, A. A.
Moore, Charles M., Jr.
Moorman, H. R.
Morris, Margaret L.
*Mouritsen, S. A.
*Moyse, Richard F.
*Moyse, Robert Keith
*Muir, J. R.
*Mulhall, M. A. E.
*Murchison, J. M.
Murphy, James B.
Myers, Wm. Howard
*Neill, Calvin F.
Nixon, Richard Arlen
*O'Bertos, John Johathon
Ogilvie, Wm. P.
Pallister, Alfred Ernest
Patterson, A. R.
Patterson, Samuel O.
Pearson, Harry
Pearson, S. G.
Phares, Wayne A.
Phipps, R. T.
*Pierce, Jack M.
*Poole, Joseph L.
*Pratt, Raymond
*Prendergast, Joseph B.
Rabey, W. N.
*Rankin, Wm. K.
*Reed, Lorne H.
*Reesor, Thomas R.
*Reford, Michael S.
Renden, Hugo R.
*Rhodes, Cecil J.
Richards, L. J.
Rickel, Wesley K.
*Robbins, Vincent L.
Robinson, Duncan B.
Robinson, John L., Jr.
Ross, Ralph B.
Rosser, B. A.
Rozsa, Theodore
Rutledge, E. E.
Sargent, D. M.
Setters, Jack
Sewell, Francis
Shell, H. E.
*Sherman, G. F.
Siegel, Frank
*Smith, David W.
Smith, James A.
Smith, J. M.
*Smith, P. N.
Smith, Warren H.
Smith, W. Gordon
Sorour, G. L.
Sosnowski, Jerzy
Sproule, J. C.
Squire, George D.
Stackler, Phil W. F.
Strand, Edwin H.
*Swanson, E. Keith
*Tessari, John Andrew
*Thomas, Howard E.
*Thomson, Alexander Brian
*Thompson, C. Grant
*Tompkins, Glen Anthony
Tucker, M. D.
*Turcotte, F. Thomas
Twardowski, C. B.
Twining, Lawrence E.
Vallat, E. H.
Van Bekkum, J. J.
*Walker, Donald James
Wallis, F. B.
Ward, John E.
*Wegemer, Richard L.
Weisbrich, R. A.
*Whitt, R. H.
Williams, Dexter E.
*Wright, Donald G.
*Wright, W. J.
Zarudzki, E. F. K.
Ziegler, James K.
Zimmerly, R. F.

**Castor**
*Gibbons, Gervase P.
♯Scheidt, Rolf W.

**Claresholm**
*Woker, L. A.

**Edmonton**
Agnew, George C.
*Adams, George W.
Austin, Harold T.
Castelli, Lou
*Chomel, D. J.
*Crane, John Donald Thomas
*Dame, A. A., Jr.
Daniel, Robert E.
*Dennis, James N.
Dickson, W. E.
Gibson, A. S.
Grimes, Joseph Walter
*Grimes, Simon L., Jr.
*Hill, Norman H.
*Jenkins, Raymond A.
Keller, Ray F.
Kittlitz, Raymond S.
*Kneale, Charles William
*Kostashuk, George
*Labicane, T. J.
*Lipsett, Lloyd R.
*MacAskill, Duncan Donald
*Morrison, John T.
Oldaker, Richard B.
*Posen, H.
*Procter, John E.
Skeels, D. C.
Tellington, W. J.
*Ustina, Frederick
*Wedin, C. R.

**Grande Prairie**
*Buckboro, K. A.
*McMillan, William R.

**High River**
Sample, J. A.

**Innisfail**
Hartman, Earl Eldon

**Lethbridge**
*Mitsunaga, Thomas T.

**Morningside**
*Sheppard, L. W.

**Oyen**
*McNeely, A. Bruce

**Peace River**
*Black, William D.
*Chalus, Walter
Chaput, U. J.
*Hudson, J. A.
Hughson, James T.
*Houston, T. G.
Kelcey, M. F.
*Lee, Loring O.
*McIvor, Donald K.
Robertson, W. A.
Schultis, Geo. E.
*Shaw, David
Stephens, J. L.
*Sutton, E. E.
*Thronton, Robin C. G.
Urich, Don L.
*Weisser, Gordon H.

**Pincher Creek**
*Lee, Alister Anthony

**Red Deer**
Blair, Wm.

**Sangudo**
*Treacy, Robert M.

**Saskatchewan**
*Hakim, Khalifa Arif

**Stettler**
*Spence, Allan K.

**Wetaskiwin**
*Miles, David Austin

**Yougstown**
*Kilback, Norman R.

### British Columbia

**Vancouver**
Adler, L.
Clark, Arthur Roy

### Manitoba

**Brandon**
*Angus, W. R.
*Kaarsberg, Ernest A.
*Wachnow, Wilfred L.

**Steinbach**
*Goossen, Harvey S.

### New Brunswick

**Bathurst**
*Mousuf, Abul Khair
*Parry, G.

### Nova Scotia

**Halifax**
♯Cameron, Robert A.

**Truro**
Blanchard, J. E.

### Ontario

**Chalk River**
Keys, David A.

**Chatham**
*Newton, A. C.

**Copper Cliff**
*Dowsett, John S.
*Taylor, Ronald R.

**Kingston**
*Fitzpatrick, Michael

**Kitchener**
♯Bergey, William R.

**Levack**
♯Spencer, E. M.

**London**
*Uffen, Robert J.

**Ottawa**
Beals, Carlyle S.
Collett, Leonard Stanier
*Garland, George D.
*Larochelle, Andre
Morley, Larry
*Wait, James R.

**Toronto**
*Betz, J. E.
Britton, John W.
Cartier, W. O.
*Clifton, Frank
♯Faessler, Walter C.
Gilchrist, Lachlan
♯Gledhill, Thomas R.
*Harvey, Herbert A.
*Hodson, J. Drew
*Johnson, A. E.
Johnson, G. R.
Keevil, N. B.
Lundberg, Hans
Mackay, Douglas Griffiths
Middleton, Brian M.
Obrien, Peter N. Somerville
♯Oldham, C. H. G.
*Paterson, Norman
*Ratcliffe, John H.
Sander, George W.

Seigel, Harold O.
#Sutherland, Don B.
*Thomson, Ker C.
*Ward, S. H.
Westrick, Edmond W.
Wilson, John Tuzo
*Winkler, Hartmut

**Quebec**

**Bourlamaque**
Brossard, Leo
**Montreal**
*Kaufman, Hyman
Stephenson, Russell W.
Salt, Donald J.
Koulomzine, Th.

**Saskatchewan**

**Eastend**
*Rosen, Ernest W.
**Moosomin**
Claus, Spencer
**Regina**
Bradford, M.D.
Carter, Roland H.
Coulter, K. C.
*Creasey, Ernest W.
Crosby, Albert P.
Dalik, C. E.
Downey, Hugh P.
*Ellard, Howard R.
*Finlay, James C.
Gibson, G. G.
*Hajash, G. M.
*Hayes, James O.
*Hutney, C. P.
Luhrs, Lawrence B.
*Mathewson, Donald
*Menzies, Arthur Whyte
*Miller, Ernest E.
Pallat, Rolf E.
*Plotkin, Max
*Post, Calvin
*Pullen, J. R.
*Randall, Peter M.
*Rothenburg, N.
*Sawatzky, Henry B.
*Steacy, John Arthur
Stoneman, Harold W.
Tims, Henry C.
Toland, David R.
*Watson, Bruce Earl
*Wolikowski, A.
**Weyburn**
*Viney, Paul Eli
*Wiber, John R.

**CHILE**

**Punta Arenas**
Breffitt, E. W.
Francis, George F.
Hernandez, R. A.
Portugal, Ramon A.
*Schneider, Oscar
**Santiago**
Grunebaum, Bernard

**COLOMBIA**

**Barrancabermeja**
*Boren, Donald E.
**Bogota**
Cowell, Frank M., Jr.
*Hays, H. Charles
Imle, Harry R.
*Milliken, Robert L.
Morales, Luis G.
*Moulton, Frank R.
Nash, Ira L.
Olson, Glen E.
Perry, Charles C.
Portwood, Thomas B., Jr.
*Stanley, P. John
Tesar, Robert M.
*Thompson, Arthur V.

**El Centro**
*Binford, James Beau

**CUBA**

**Havana**
Bornemisza, Stephan
Thyssen

**DENMARK**

**Copenhagen**
Lundbak, Asger N.

**EGYPT**

**Alexandria**
Hodge, Paul V.
*Runte, F. C.
*Russell, Willie Lee, Jr.
Strong, J. Randolph, Jr.
**Cairo**
Bixby, Robert H.
Cochrane, David W.
Eicher, Donald B.
King, Laurence K.
*Wafick, Mohammed

**ENGLAND**

**Birmingham**
Polak, Edward Jan
**Cambridge**
#Belshe, John C.
**Edgeware**
*Murray, Arthur
**Glam**
*Rees, J. C.
**Holwood, Keston**
*Anstey, Nigel A.
*Bennett, Geoffrey L.
Bourne, I. C. J.
*Brummit, J. G.
*Campbell, F. J.
*Cruickshank, James W.
Dod, G. F.
Edwards, Thomas Ellis
Fitch, A. A.
Graf, Victor V.
Hales, F. W.
Hartley, D. A.
*Haskett, R. W.
*Heads, J.
*Lee, Maurice Leonard
Lindsey, E. B.
*Marshall, John K.
*McPhee, William S.
O'Brien, Terence
Packer, Albert George
Pezarro, Theodore A.
Smith, J. K.
Van Der Linden, E. J. P.
*Van Der Linden, E. P. E.
*Young, Wm. M.
**Sussex**
*Morrison, Trevor W.
**Liverpool**
*Wilson, C. D. V.
**London**
Brown, F. W.
Davies, Richard
*Domzalski, W.
Dundon, Robert F.
George, W. J.
Germain-Jones, D. T.
*Hodges, William George Hamer
Malone, Adam B.
*Randell, John T., Jr.
Richards, T. C.
Robertshaw, J.
**Newark**
Lamont, A.
*Winstanley, Oliver B.
Wyrobek, S. M.
**Scarborough**
*Ley, J. R.
**St. Albans**
Tait, George
**Weybridge**
Tarrant, L. H.
**Yoevil**
*Hebditch, G. E. W.

**FINLAND**

**Abo**
Metzger, Adolf A. T.

**FRANCE**

**Begles**
Brewer, Herbert L.
Schultz, F. E.
**Lorient**
*Gondouin, Michel
**Montpellier-Herault**
Grepin, André
**Paris**
Aynard, Claude
Baboin, Guy E.
Baranov, Vladimir
Beaufort, Lucien
Bouchon, Rene Philippe
Cagniard, L.
Genesley, Raymond H. J.
Giraud, Paul
Goguel, Jean
Henquet, R.
Kunetz, Gesa
Leblanc, Jacques
Le Saget, Andre
Maillet, Raymond J.
*Mainguy, Maurice
Mathiez, Jean Paul
*Migaux, Leon
Pieuchot, M.
Richard, Henri
Roger, A. H.
*Royer, G.
*Saint-Legar, Yves
Sundt, Olaf F.
**Pau**
Dienesch, Jean
**Rueil-Malmaison**
#Heritier, Francis E.
Mouche, Theodore J.
*Schwing, Edward H., Jr

**GERMANY**

**Barkhovenalle**
##Mintrop, L.
**Berlin-Lichterfelde**
Stubbe, Gerhard
**Bonn**
Rosenbach, Otto
**Hannover**
Gees, Rolf Heinz
Heimburg, Fritz
Maass, Hans Wilhelm
Schulze, Gustav-Adolf
Von Helms, Hans
Zettel, Waldemar
**Ludwig**
Schleusener, Alfred
**Sachsen**
Kaselitz, Fritz

**GUATEMALA**

**Guatemala City**
*Seidner, Edmond

**HAWAII**

**Hawaii**
*Eaton, Jerry Paul

**HONG KONG**

**Hong Kong**
Fu, C. Y.

**ICELAND**

**Reykjavik**
Bodvarsson, Gunnar

**INDIA**

**Calcutta**
Caan, A. J. Z.
Craig, Robert L.
Hazra, P. C.
Negi, B. S.
Rao, M. B. Ramachandra
Rao, Suryanarayana M. M.
Sengupta, S. N.
Simha, K. R.
**Delhi**
Chandiok, K. C.
**Digboi**
*Awasthi, Anand Mohan
*Narayana, J. V. S.
**Kharagpur**
Bhattacharya, Prabhat Kumar
Roy, Amalendu
**Poona**
Banerjee, Santi Lal

**INDONESIA**

**Djakarta**
Hill, Robert G.
**Pakan Baru**
*Van Der Harst, L.
**Palembang**
Dahlberg, Jack K.
Irby, W. L.
Jones, Enoch Gerald
*Kleyn, A. H.
Murray, Matthew T.
Morse, Dwight P.
*Rodgers, Leo
Walton, James I.
Winkler, B. O.
**Wonokromo**
Balmforth, David Michael
Kok, G.

**IRAN**

**Masjid**
*Tuman, Vladimir S.

**IRAQ**

**Basrah**
*Jaka, Jack G.

**IRELAND**

**Belfast**
*Reid, T. J., Jr.
**Tullamore,**
*Heelan, Patrick A.

**ISRAEL**

**Jerusalem**
Franklin, Louis
**Kfar Shmaryahu**
Lohnberg, A.
Lohnberg, E.
**Rehovot**
Behr, M. I.
Pekeris, C. L.

**ITALY**

**Cagliari**
Belluigi, Arnaldo
**Forli**
Ross, Joseph Clinton
**Lodi**
Selem, A. M.
**Milano**
*Amato, John J.
Bernasconi, Carlo
Bossolasco, Mario
*Calledare, Wm. C., Jr.
*Heaney, Don
Rocco, T.
Solaini, Luigi

**Napoli**
Dessau, Gabor
**Rome**
Kafka, Fred T.
**Trieste**
Morelli, Carlo

### JAPAN

**Akita-shi**
Tazime, Kyozi
**Fukuoka**
Onodera, Seibe
**Nagoya**
Iida, Kumiji
**Tokyo**
Omote, Syunitiro
**Yamaguchi Pref.**
Katayose, Kuniyuki

### LEBANON

**Tripoli**
Banta, Norman Hollis
*Chubb, Lewis Orr
Colley, G. C.
*Collier, John Veasey
Grimes, Thomas E., Jr.
Van Der Plaats, H. J.

### LIBYA

**Tripoli**
*Shaffer, Richard E.

### MEXICO

**Mexico City**
Aldredge, R. F.
Alverez, Manuel, Jr.
Blackledge, Glenn E.
*Castillo-T, C.
Daly, W. W.
*Escamilla, Henry G.
Fredin, David Herbert
Frost, Noel
*Garduno, A. R.
Holbert, Murrell
Kohler, G. J.
*Kumpel, George F.
Moedano, G. H.
Moody, N. K., Jr.
*Munguia, E.
Olhovich, V. A.
Orozco, E.
Ortiz, Thomas
Rockwell, Donald West
Rojas, A. Garcia
Schoellhorn, Henry, III
Thomas, J. W.
**Obregon**
Lopez, R. Monges
**Tampico**
Roose, Donald D.

### MOROCCO (FRENCH)

**Petitjean**
Schoeffler, Jacques

### NETHERLANDS

**Geleen**
Van Riel, W. J.
**The Hague**
Baars, B.
*Bakker, Gerrit
Brown, Donald R.
Hofman, B. J.
Johnson, Curtis H.
Koefoed, Otto
Van Keulen, Johannes
Van Weelden, A.
**Landsmeer**
*Herfst, A. B.
**Leidschendam**
Deblank B.
**Mantgum**
Zijlstra, Nico
**Oldenzaal**
Snyders, G. H.
**Wassenaar**
Debruyn, J. W.

### NEW GUINEA

**Port Moresby**
*Jeffries, F.
**Papua**
Steer, Mervyn D.
**Sorong**
Brons, H. H.
*Kaan, J. F.
*Marshall, Lain
Van Der Schraaf, N.
Van Der Syp, J. W. C. M.

### NIGERIA

**Kaduna**
*Walls, R.
**Owerri**
Jackson, J. B.
Velzeboer, Cornelis J.

### NORWAY

**Trondheim**
Logn, O.

### PERSIA GULF PORTS

**Doha, Qatar via Bahrain**
*Barkouky, A. N.

### PERU

**Arequipa**
*Baldwin, Robert W.
**Lima**
Albright, E. Glenn
**Talara**
#Smith, Clark H.

### PHILIPPINES

**Manila**
*Aycardo, M. M., Jr.

### PORTUGAL

**Lisbon**
*Goncalves, Carlos

### PORTUGUESE EAST AFRICA

**Mozambique**
Barbour, P. C.
*Bohanan, Wayne F.
Heggblom, J. Conrad
Spoor, Arnold

### PORTUGUESE WEST AFRICA

**Luanda**
Linwell, Martin V.
#Novotny, R.

### RHODESIA (Southern)

**Bulawayo**
Fletcher H.
**Salisbury**
Jordan, John N.
**Sinoia**
*Searls, Robert J.
#Wieduwitt, William G.

### SAUDI ARABIA

**Dhahran**
Beverly, Burt, Jr.
*Garvey, Thomas A.
*Hill, Brian Bernard
*Hoke, John H.
*Jones, George R.
*Price, Lee H.
Reed, I. J.
#Sabity, Al
Seager, O. A.
*Sheehan, James B.
*Spivey, Sherman Rex
*Wimpey, Lawrence Gill
Zimerman, Sam

### SOMALIA

**Mogadiscio**
Kerr, Charlton
*Lea, Milton H.

### SOMALILAND

**Mogadiscio**
Talty, Russell H.

### SOUTHWEST AFRICA

**Tsumeb**
Hunter, Kenneth Edward

### SURINAM

**Paramaribo**
*Schols, H.

### SWEDEN

**Boliden**
Malmqvist, David
**Stockholm**
Hedstrom, Erik Helmer
Johansson, Bertil
Tornqvist, Gosta
Werner, Sture

### SWITZERLAND

**Geneva**
Poldini, E. M.
**Zurich**
Fisch, W.
Gassman, Fritz
**Wirzenweid**
Susstrunk, August E.

### TUNISIA

**Tunis**
*Dekker, Dirk
Hartmann, P. C. P.
Mrosovsky, Peter

### TURKEY

**Ankara**
*Diker, Salahi
*Dizioglu, Mehmet Yusuf
Ergin, Kazim
#Yazici, E.

### UNION OF SOUTH AFRICA

**Johannesburg**
Lowenstein, N.
Paver, C. L.
**Pretoria**
Enslin, J. F.
Maree, Burgert D.
Vegter, Johannes R.
**Welkom**
*Hoogenhout, W.

### URUGUAY

**Montevideo**
Leggett, J. Ridgely

### VENEZUELA

**Barcelona**
*Coughlin, Edward G.
Kibby, T. A.
*Mahaffy, Earle F.
**Caracas**
Avenius, Rodney G.
Baber, A.
Baker, Malcolm C.
Beaver, Jay George
Blomerth, Elmer Alexander, Jr.
Browning, Paul F.
*Burr, Neal W.
Cerveny, Philip F.
Chapman, William M.
Conrad, P. P.
Copeland, Harold L.
Couch, Robert G.
Dorris, James E.
Dortch, Willis R., Jr.
*Drake, William R.
*Dranke, Marvin E.
Driver, Edgar S.
*Edge, Julius P.
*Erwin, William M.
Fellows, W. L.
Fetzer, E. L.
Franks, W. E.
Gilbert, Rowland K.
Greener, Charles E.
*Heilmann, Gerrard G.
*Hilliker, Robert Dean
Jacobsen, Peter, Jr.
Johnson, Hamilton M.
Judson, Lewis Frederick
Keeling, J. A.
Kitch, Ronald R.
*Klima, Francis R.
Krum, Wm. K.
*Laidlaw, Wm. H.
Laubscher, Hans P.
Letourneau, P. R.
McKee, James B.
McLay, James H.
Merrill, William Raymond
Merritt, W. C.
Montgomery, John A., Jr.
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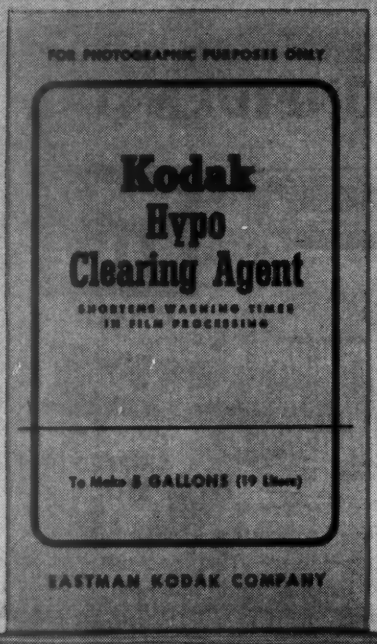


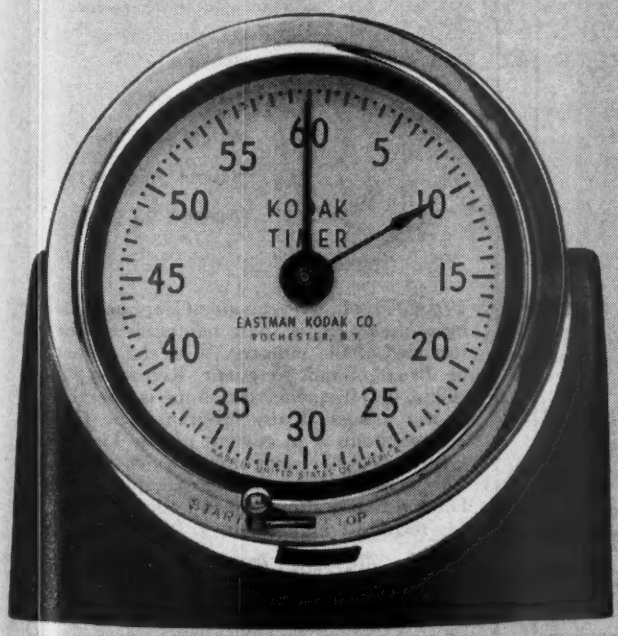


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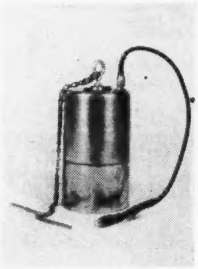

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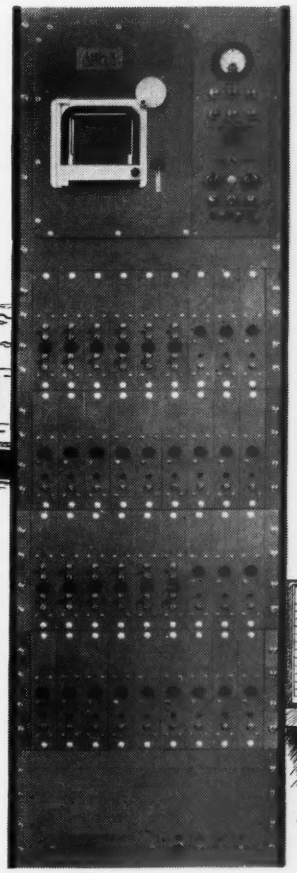

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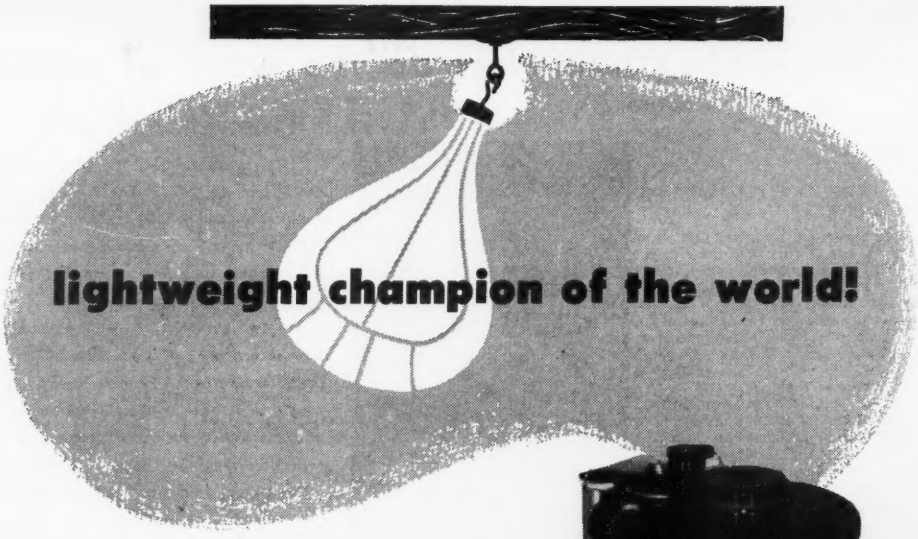

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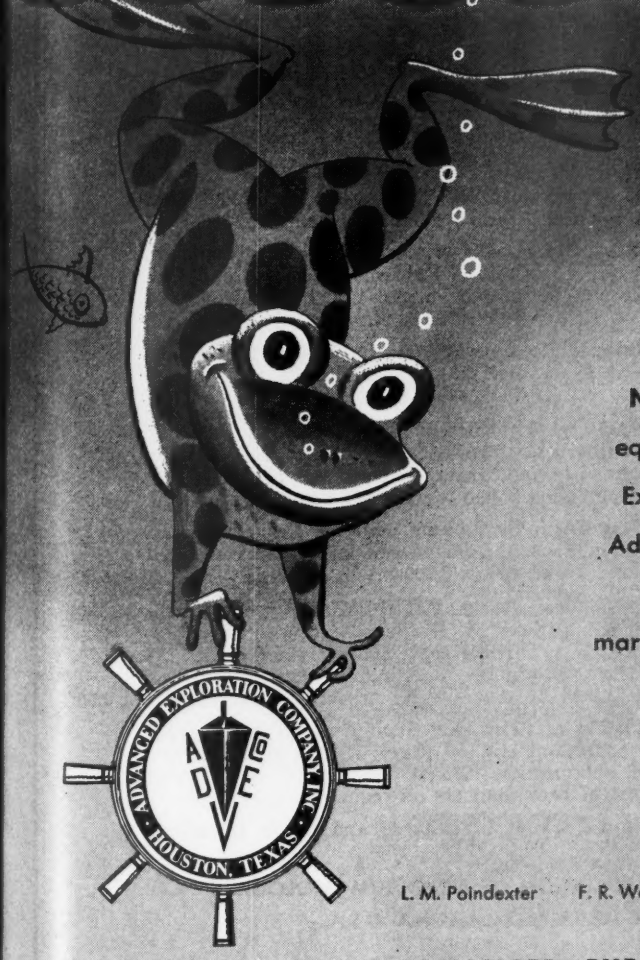


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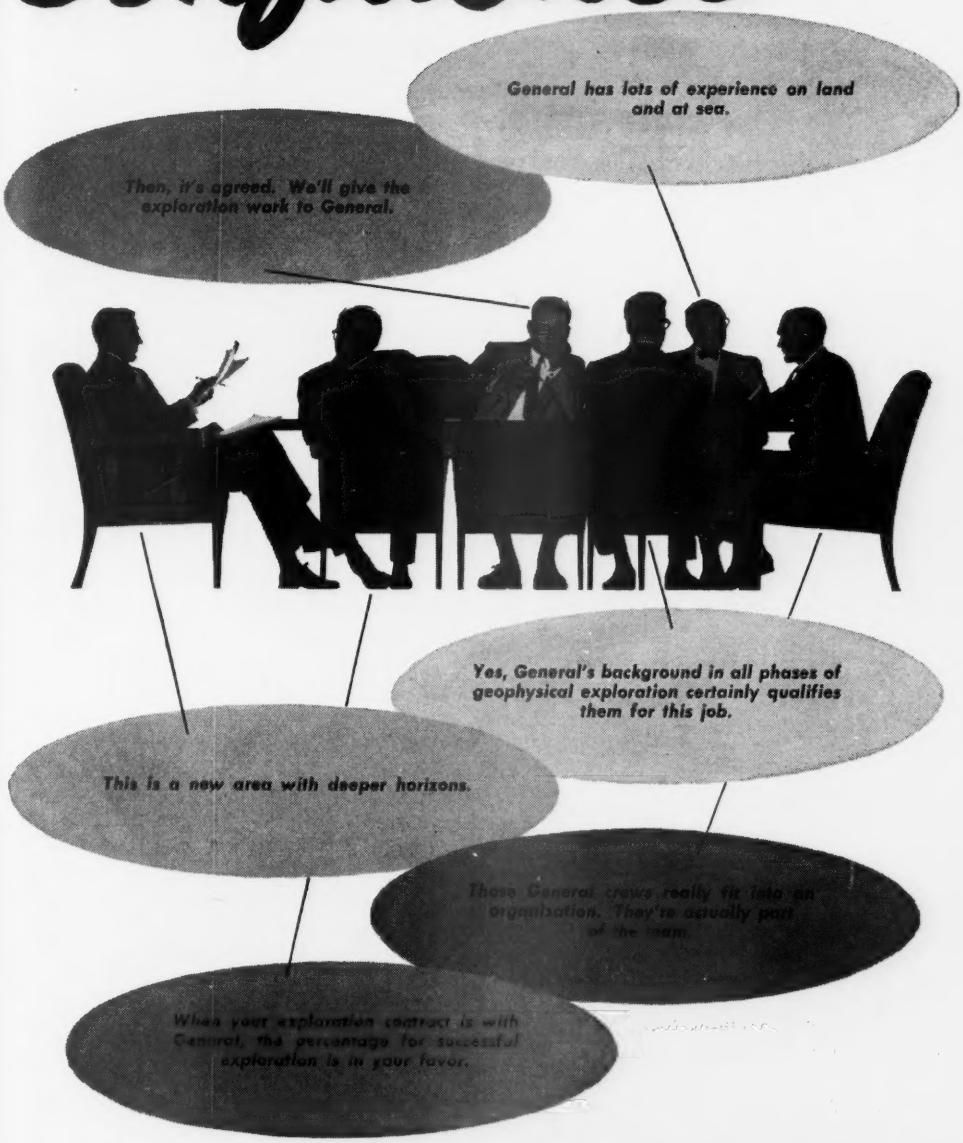
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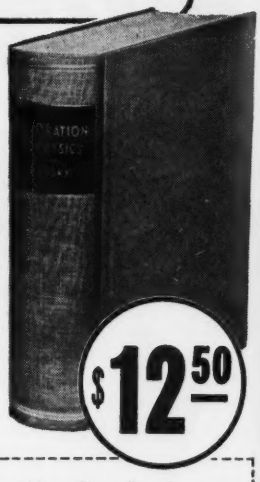

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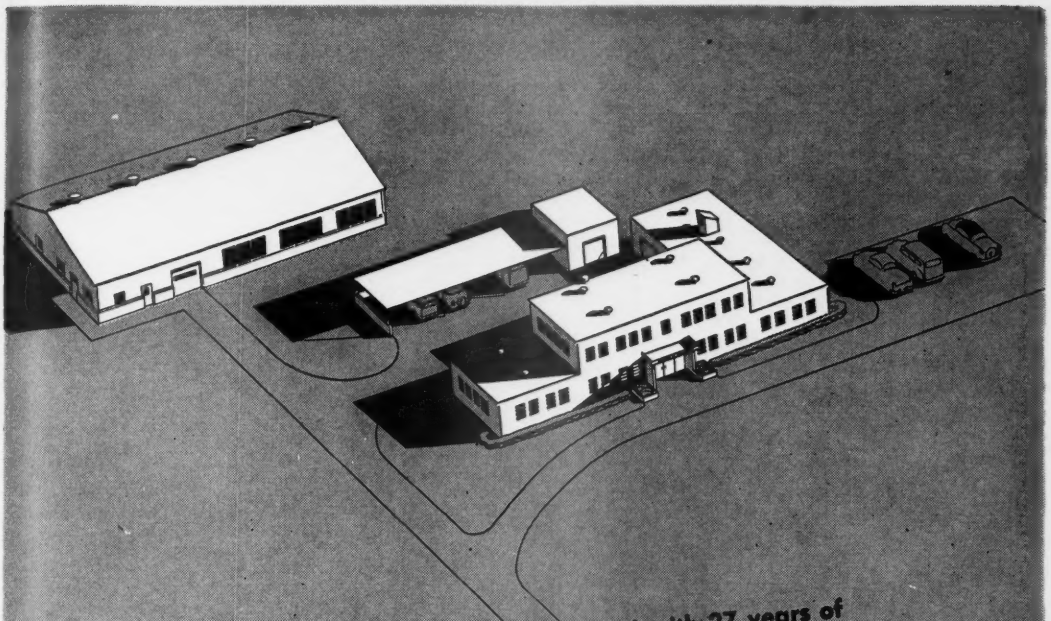

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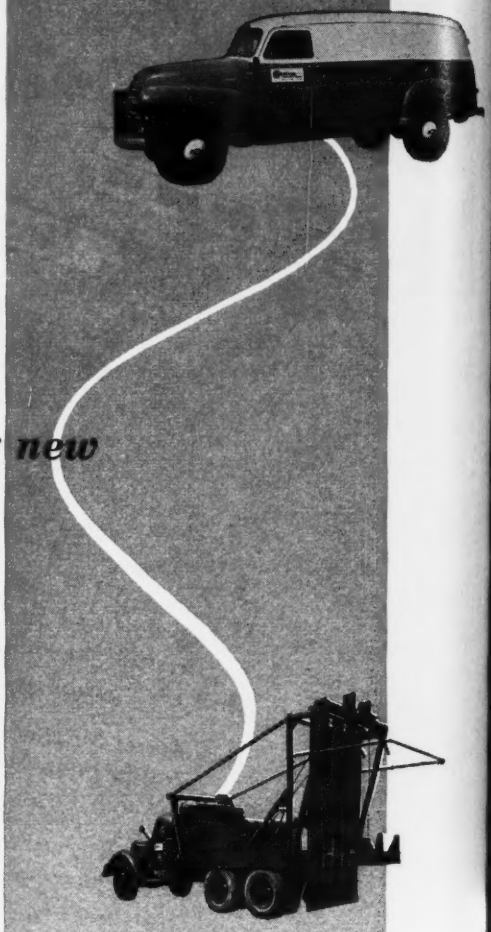

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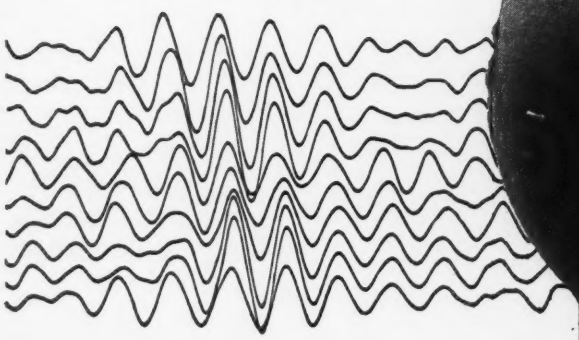

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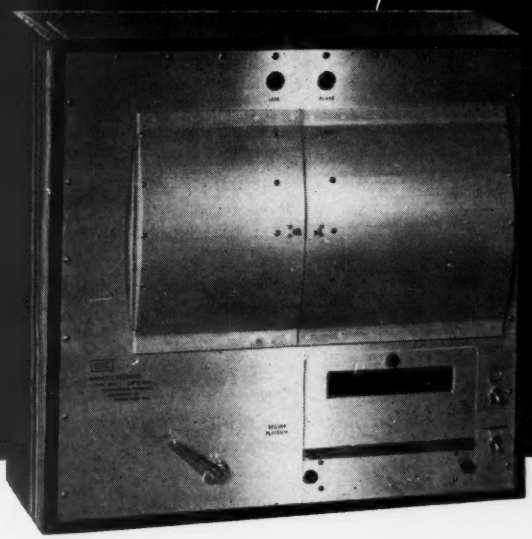

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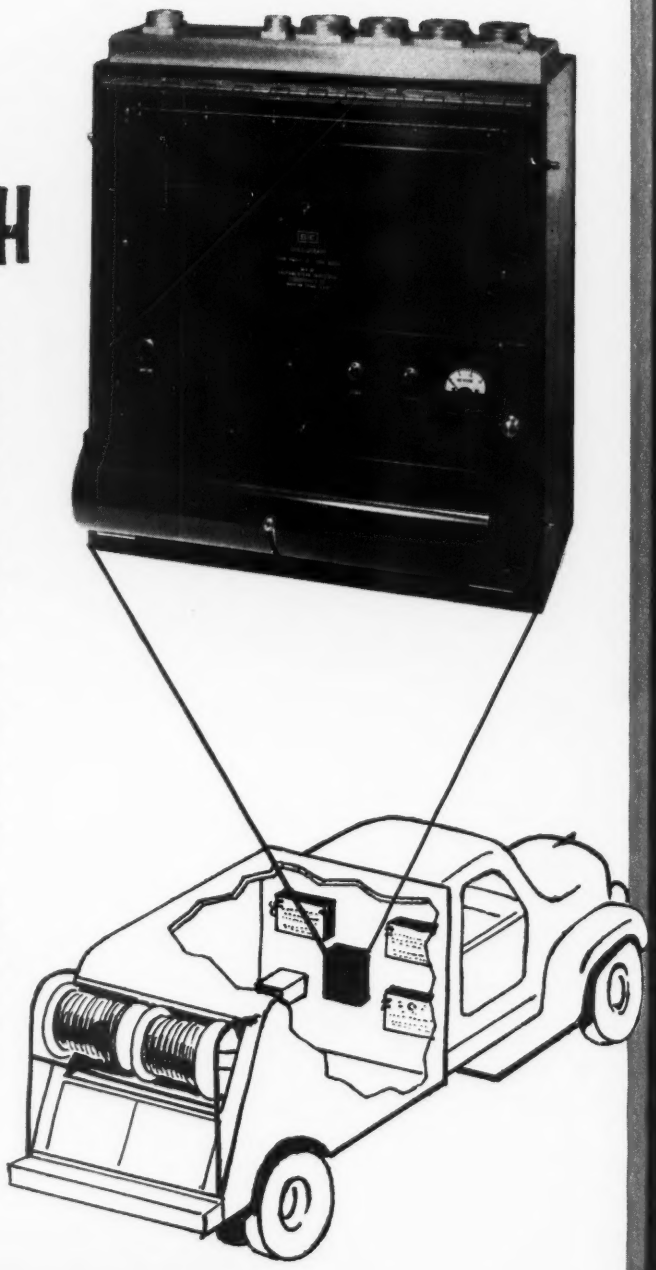

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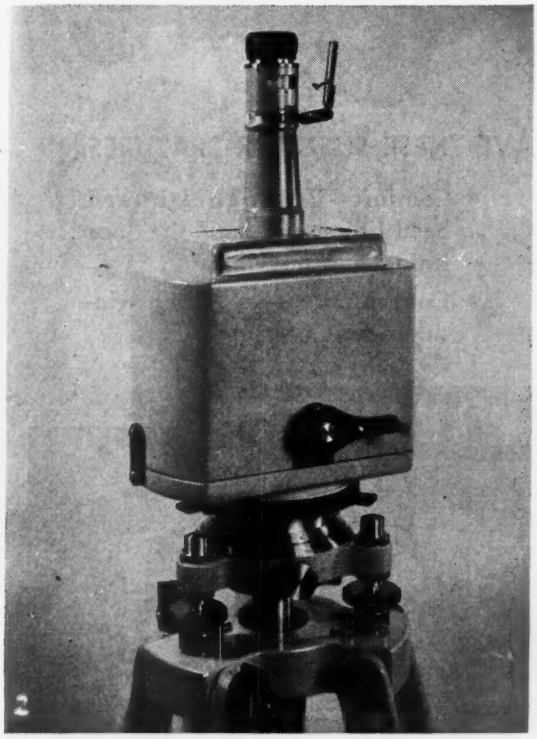

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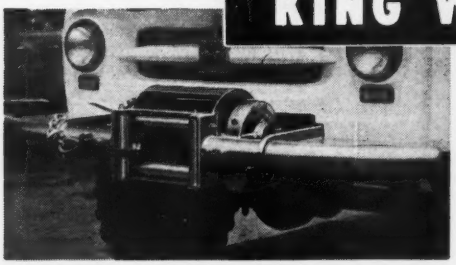

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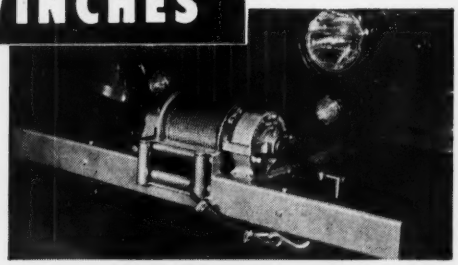

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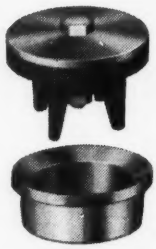

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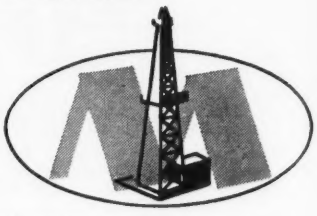

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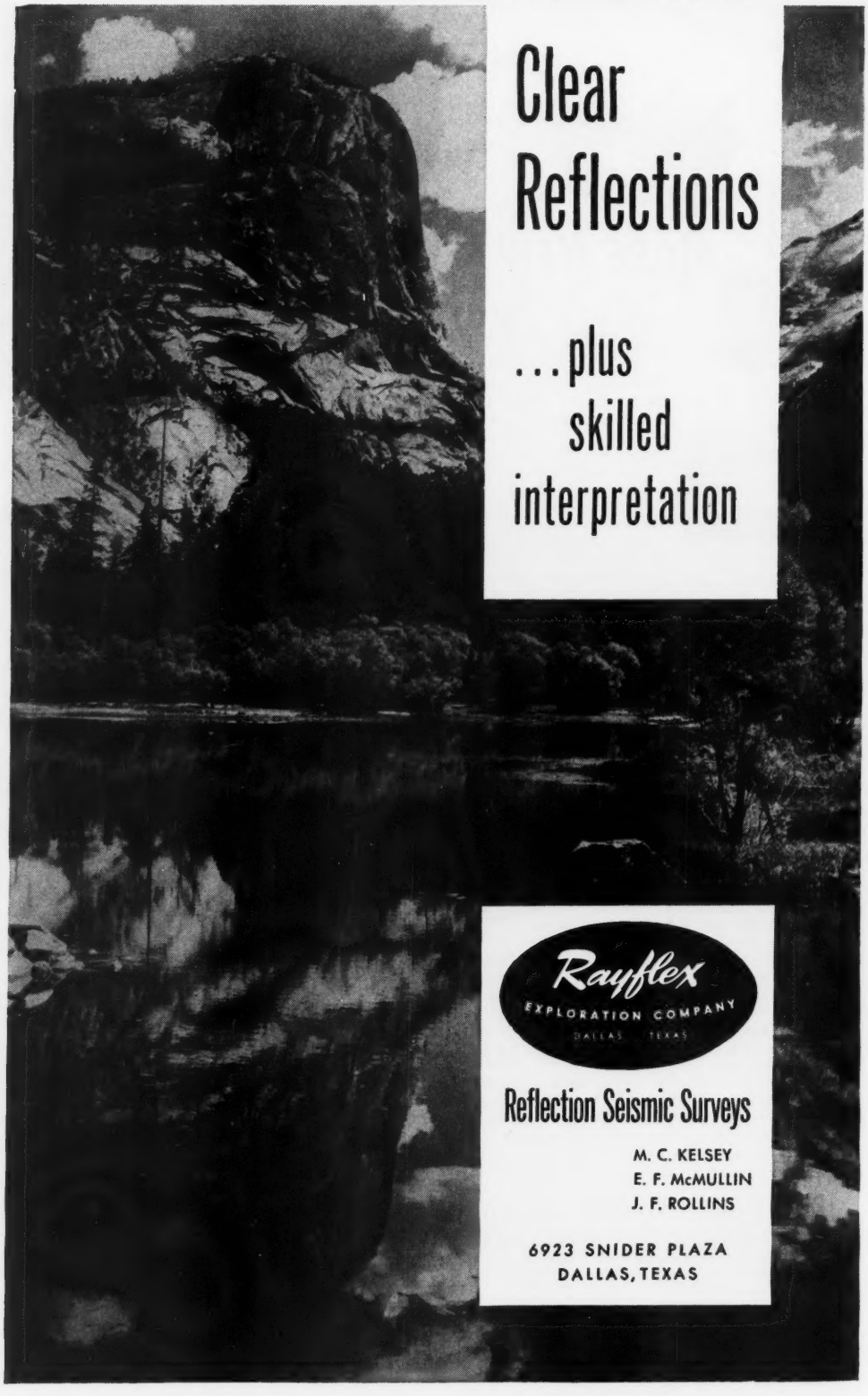
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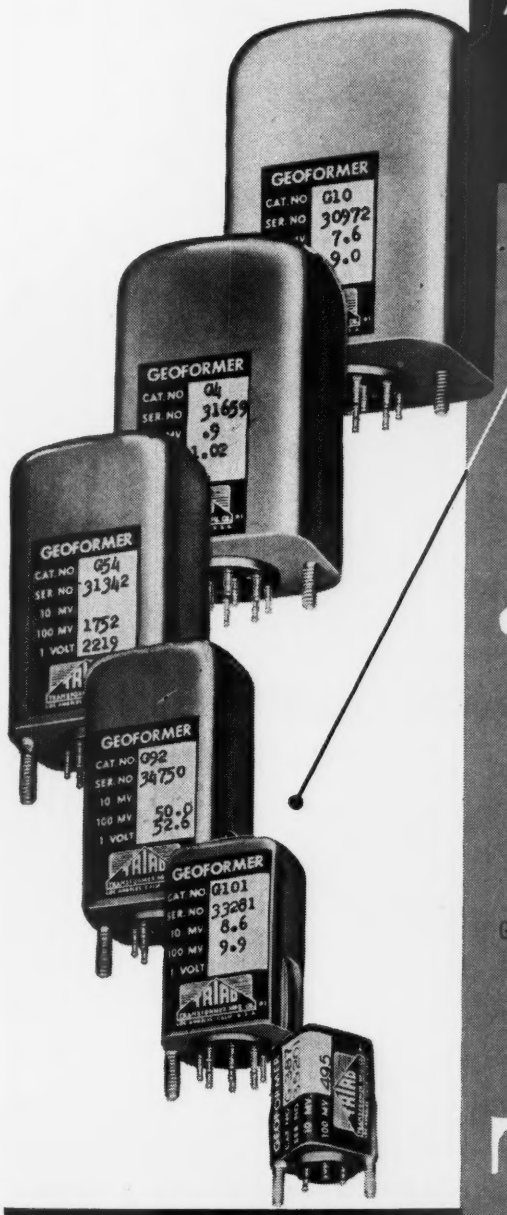


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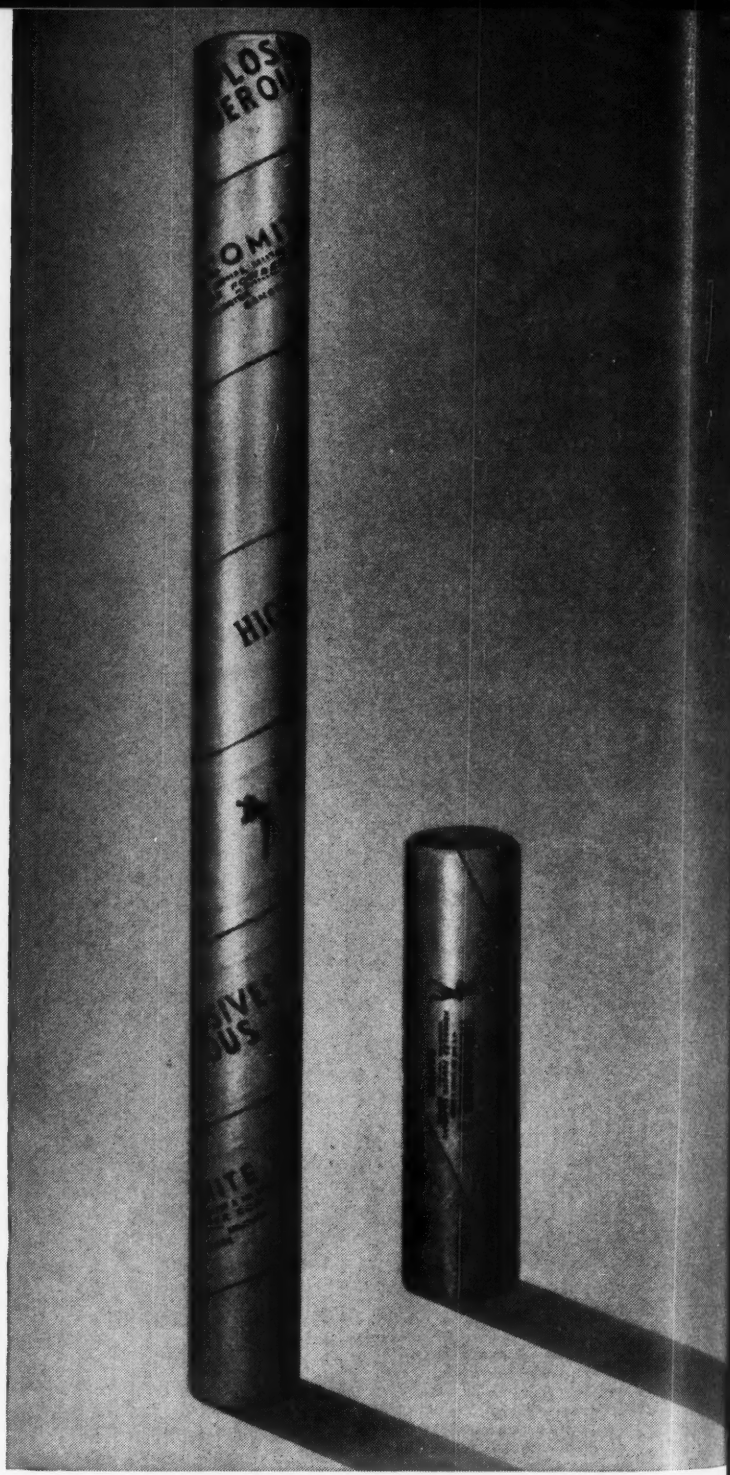

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The HTL Model 7000 gives you unchallenged superiority in distortion control and sensitivity with an input range from 0.1 microvolt to 0.1 volt between 10 and 200 cycles with less than 1% harmonic distortion. Unique filtering flexibility — 1380 filter combinations — plus advanced two-loop Automatic Gain Control add to the versatility of this new seismic system. AGC speed control on each channel provides a choice of three positions — slow, medium, or fast.

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| 1,000,000 to 1 dynamic range | input signals as low as 0.3 microvolt saturate AGC (AGC threshold 0.1 microvolt) | 1380 possible filter combinations | negligible distortion up to 0.1 volt input | built-in complete testing facilities |

| | | | |
|---|---|---|---|
| module construction for portable or vehicle use | ideally suited for magnetic recording | linear, time-varied gain, or AGC operation | three AGC speed positions on each channel |

**WRITE for HTL Bulletin No. S-304 for more detailed information about this completely new development in seismic instrumentation. Model 7000 systems now in production and available.**

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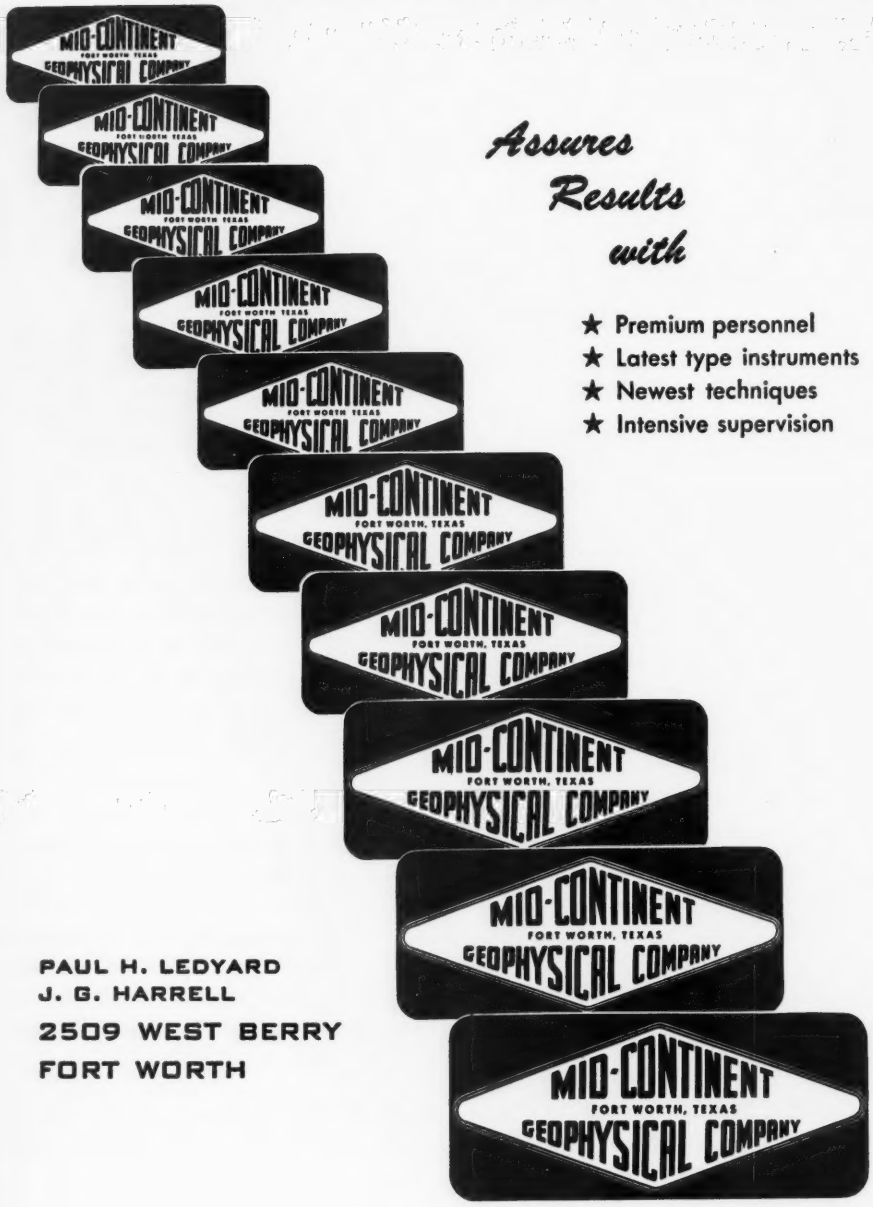


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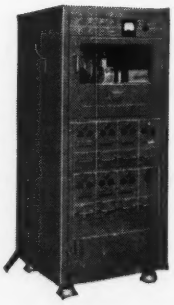
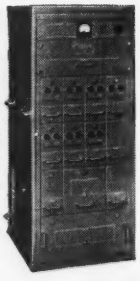


**RECORDER** is designed for truck mounting, magnetically records 28 data channels and provides written monitor record.



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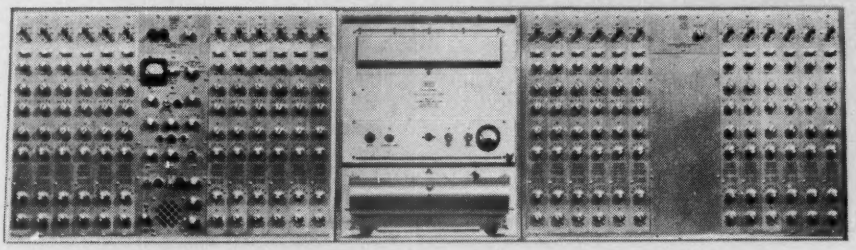

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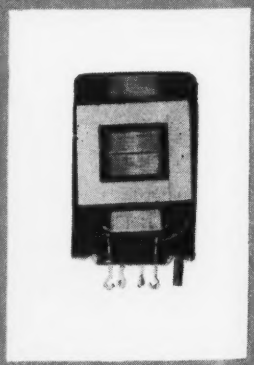

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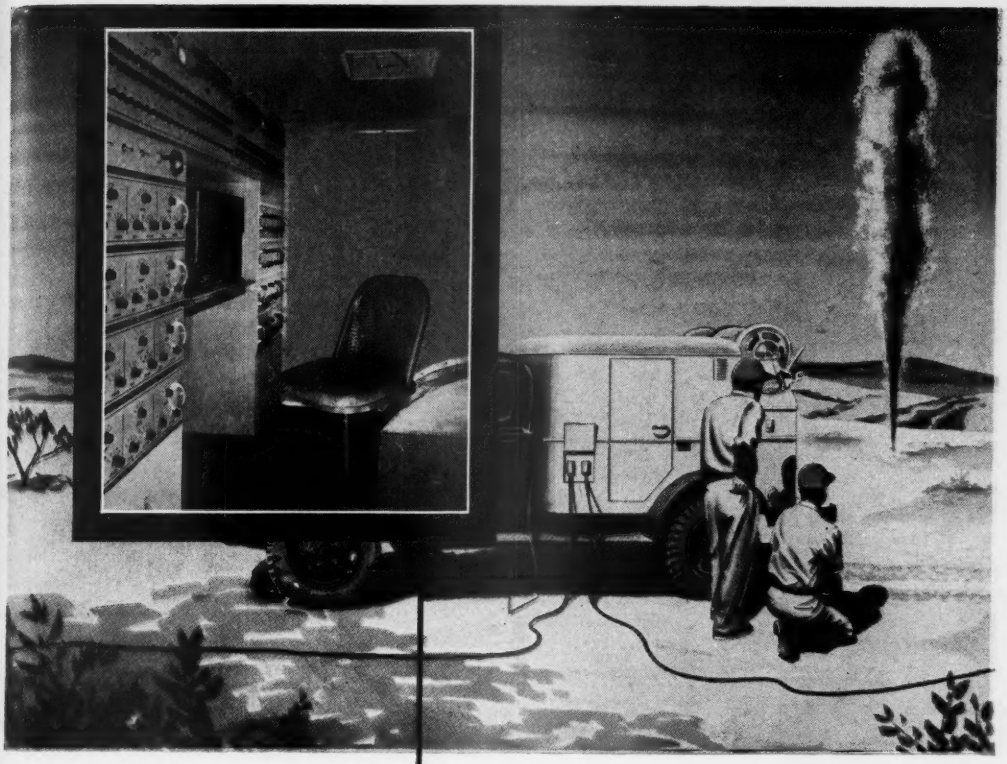

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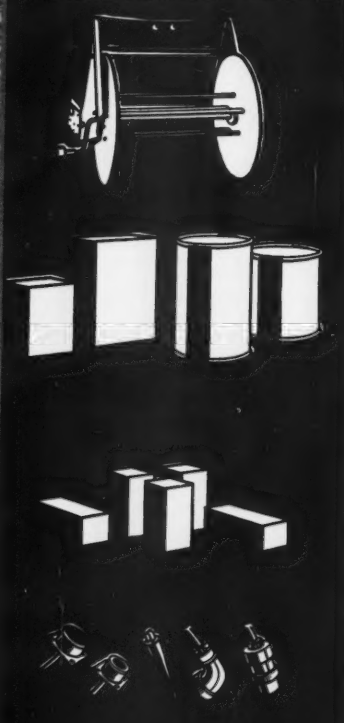

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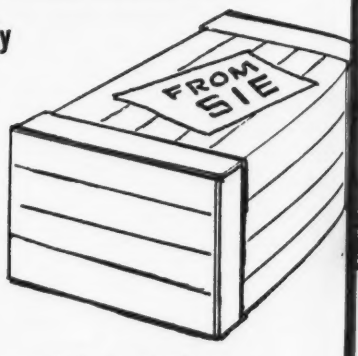


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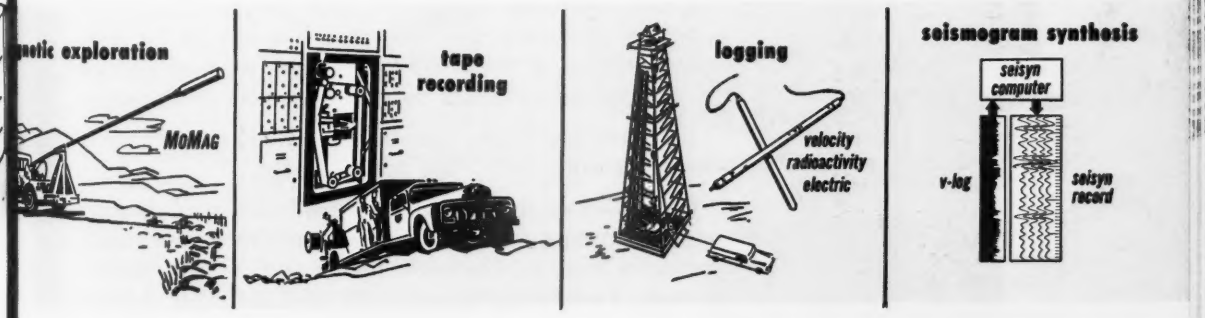


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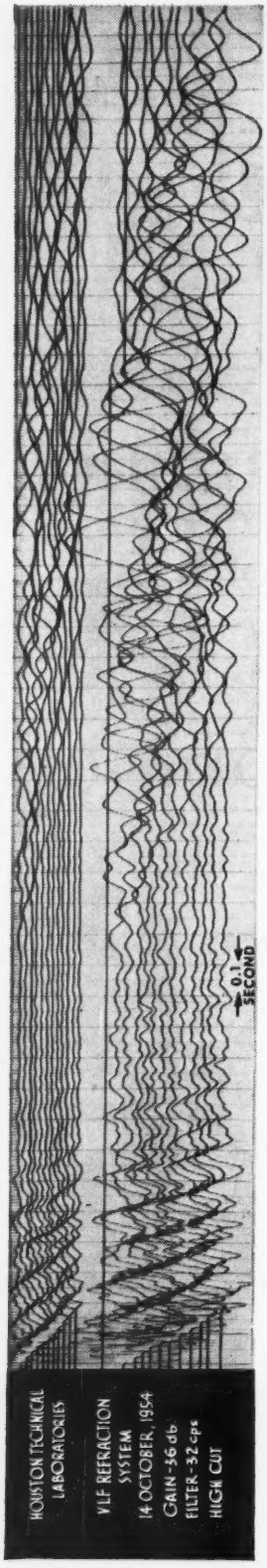


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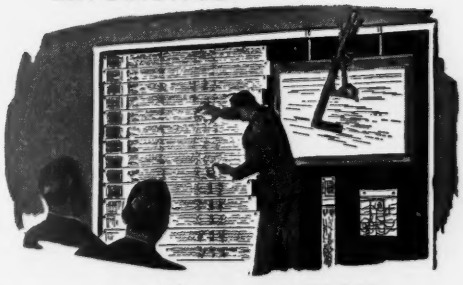

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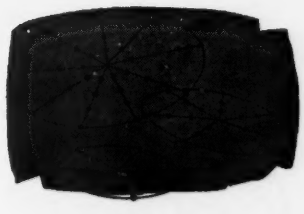

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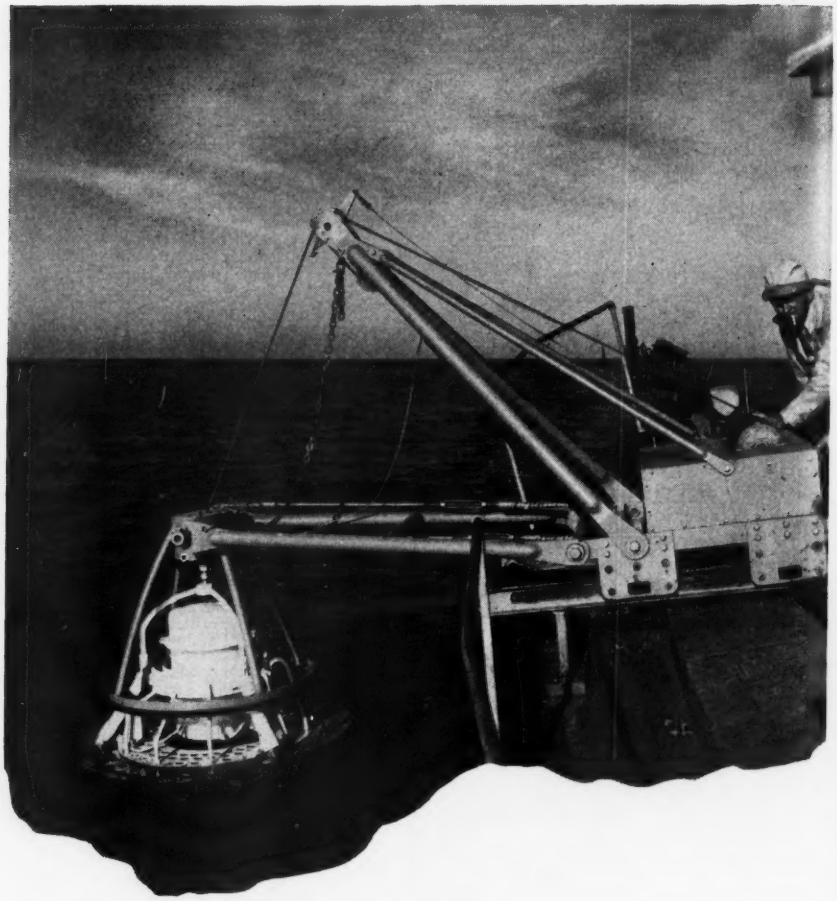

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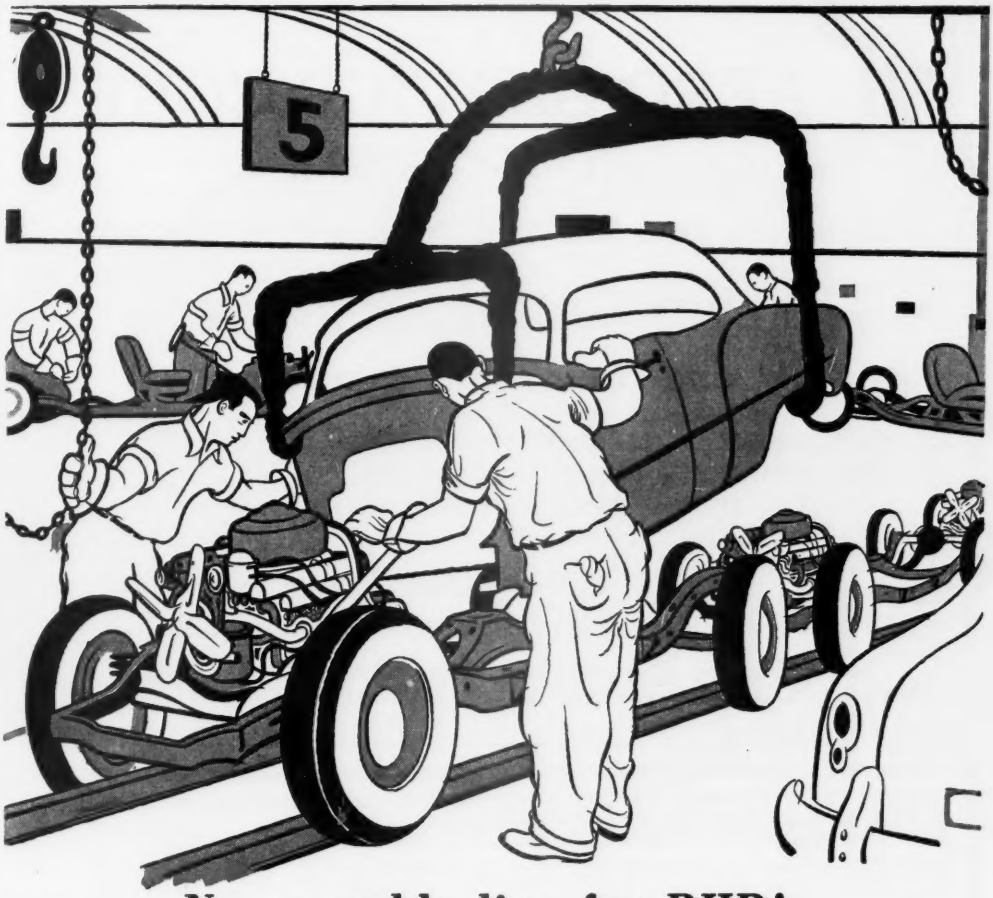


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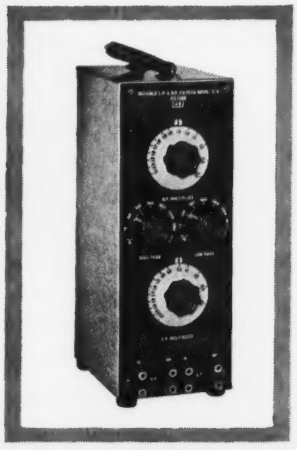

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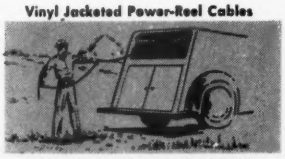

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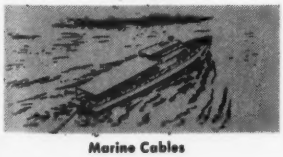

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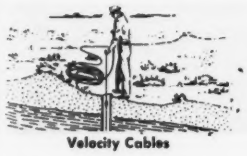

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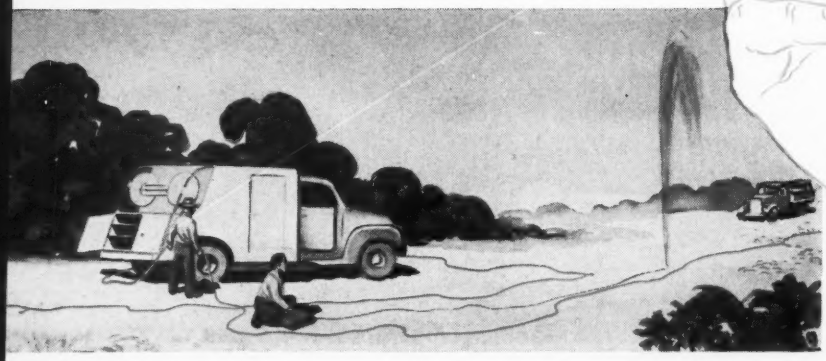

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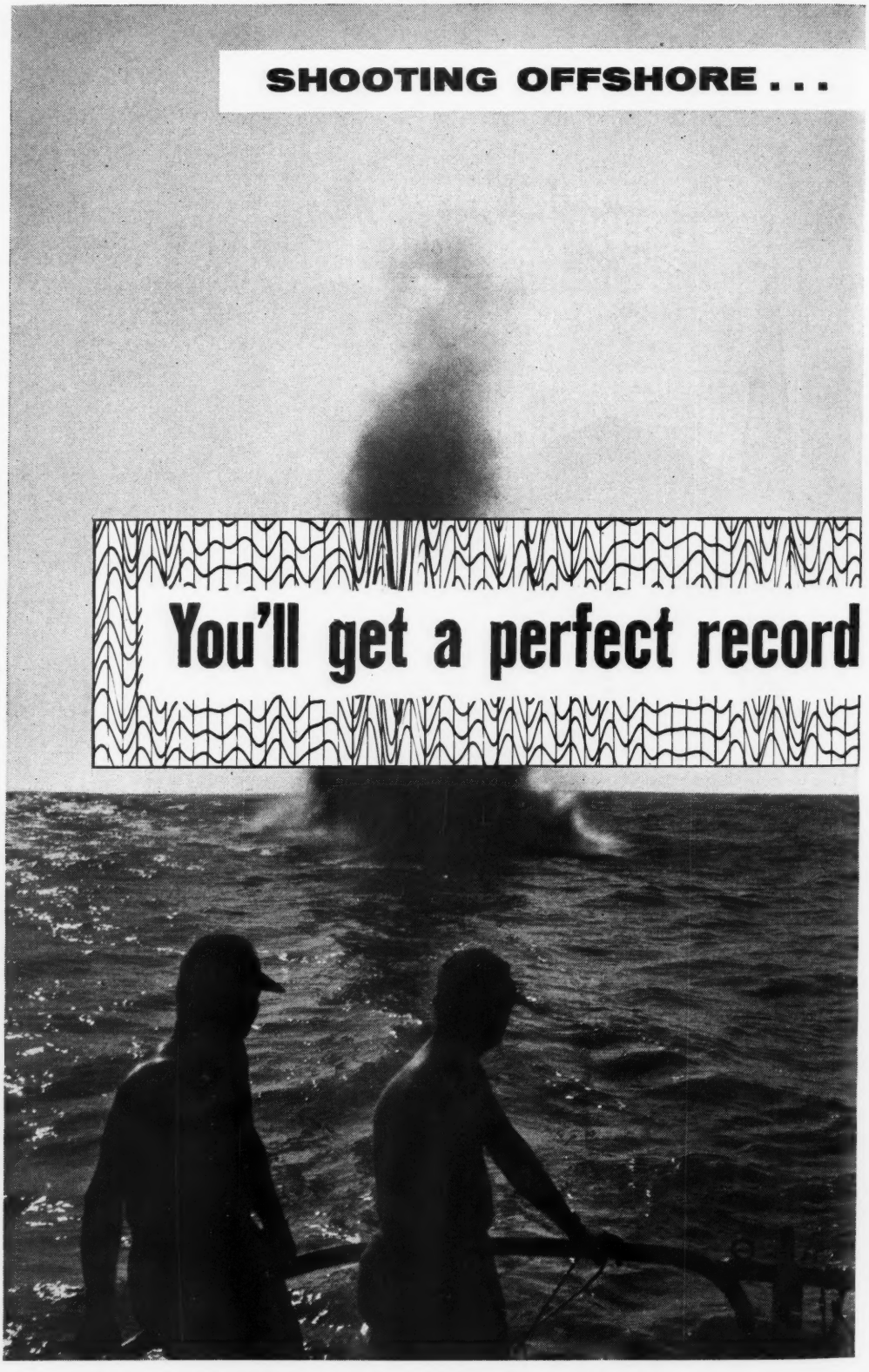
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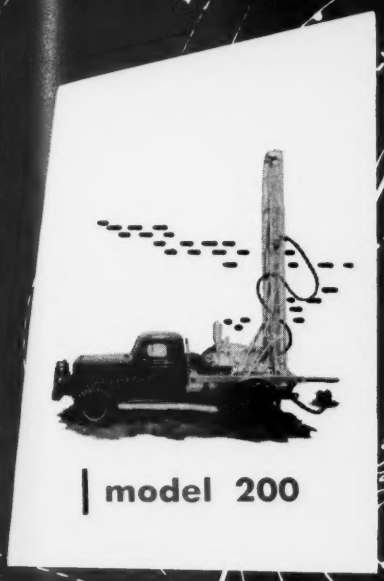

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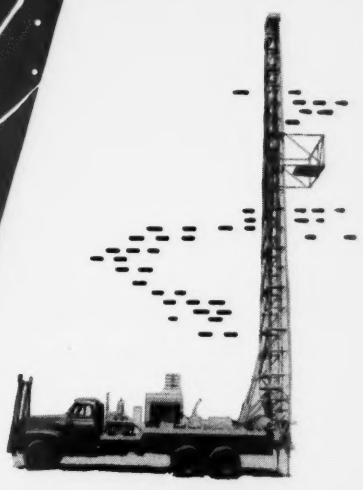

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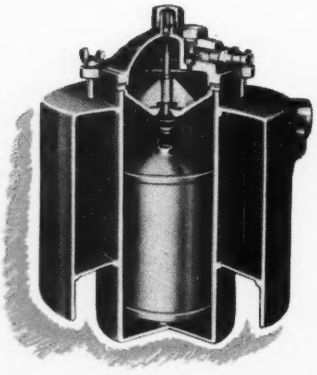

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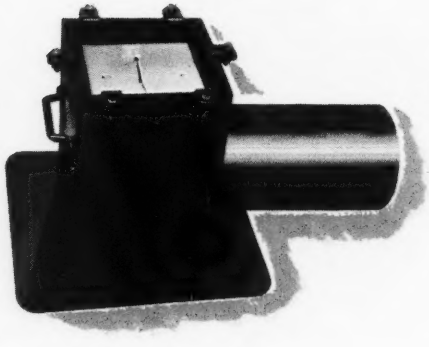

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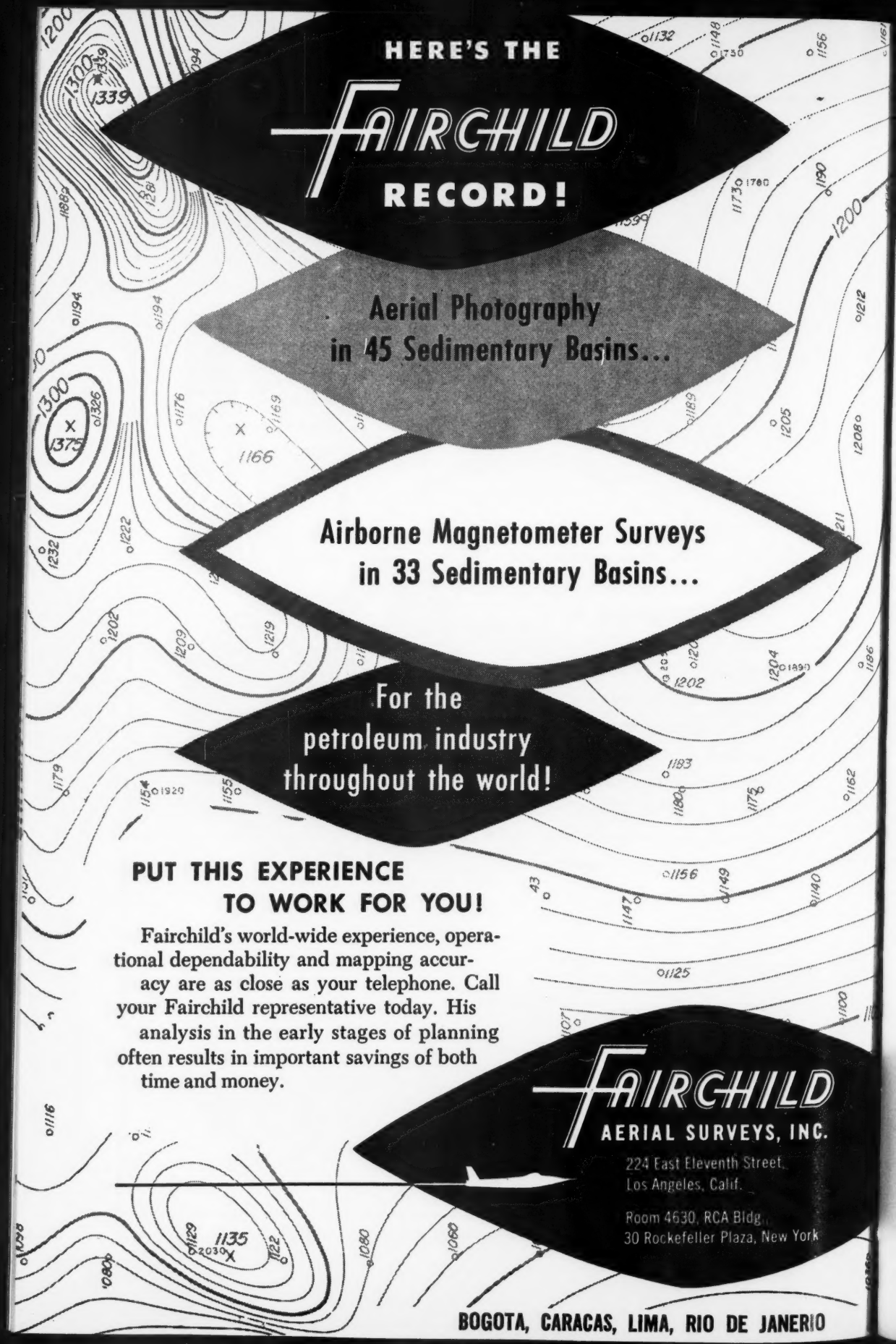
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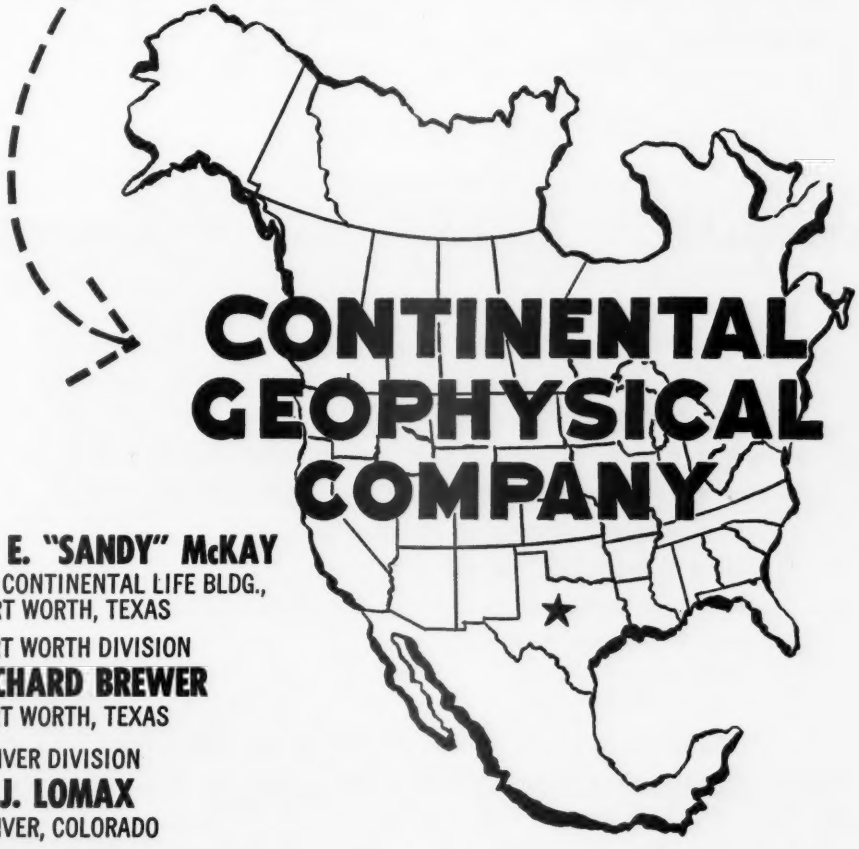

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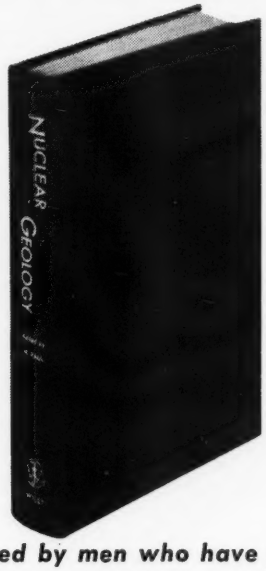


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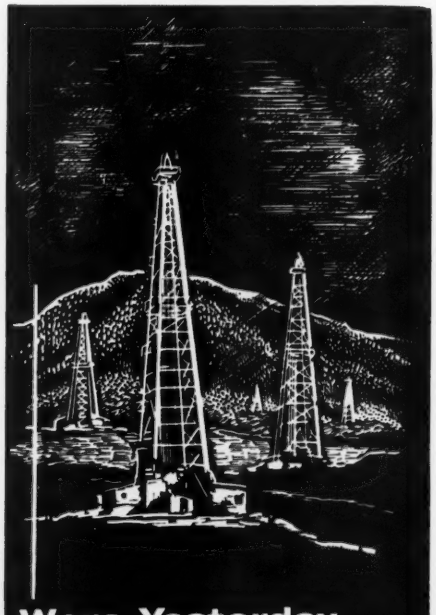

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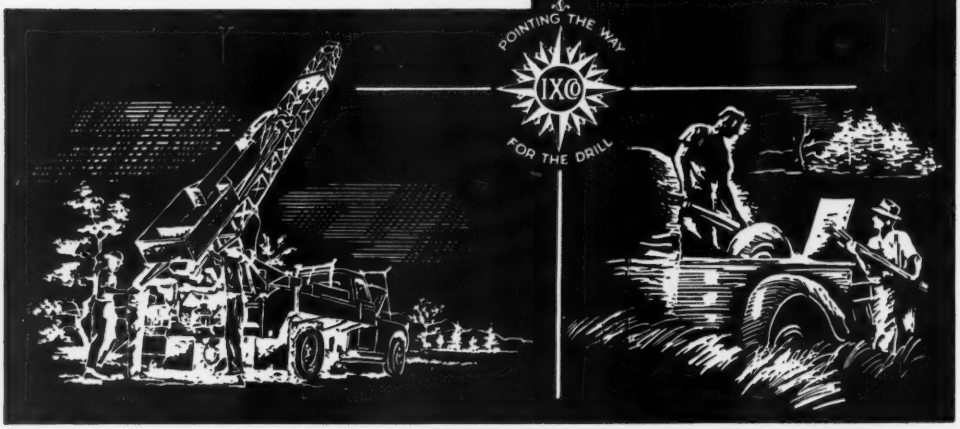


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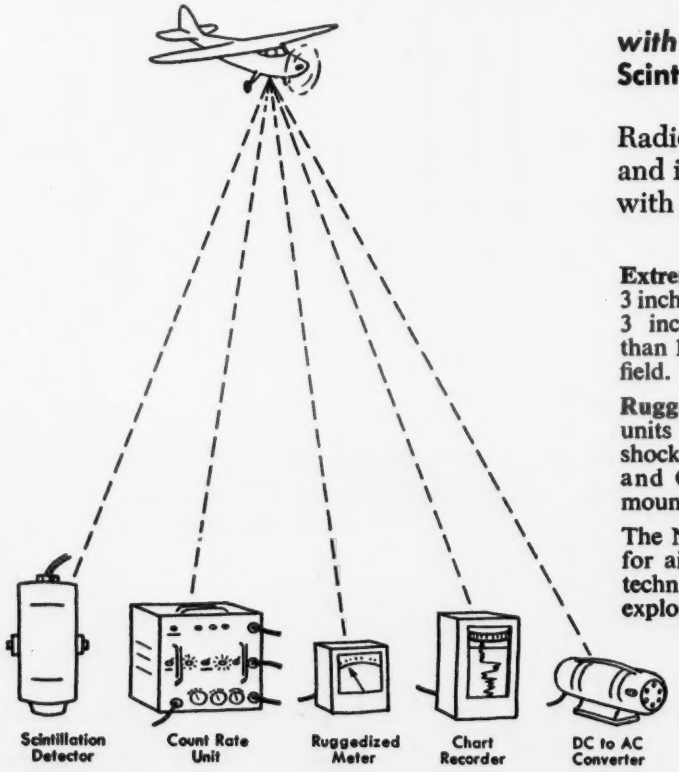


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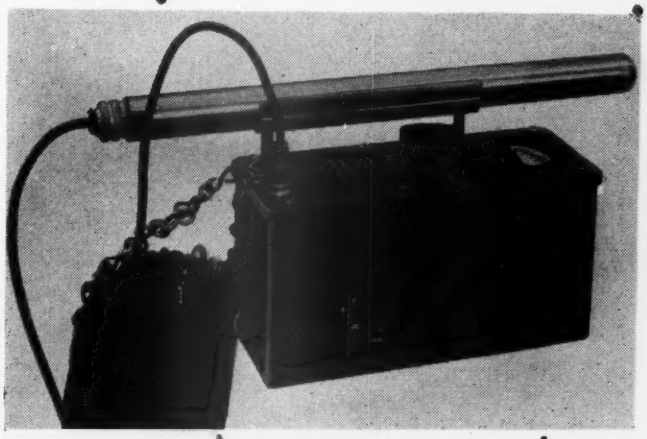

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